ABSTRACT

STEVEN JAMES COOPER. Evaporation of a Mineral Oil in a Mist Collector. (Under the direction of DAVID LEITH)

Many industrial processes generate mineral oil mist. Current control technologies focus only on removing the mist droplets from the air. However, if these droplets evaporate, the vapor can pass through a collector designed to remove droplets alone. The purpose of this study was to determine the extent of evaporation for mineral oil droplets introduced to a mist collection system. Vapor was sampled using activated carbon downstream from the collector as high concentrations (45-55 mg/m^3) of oil mist were injected upstream. After the system was loaded with mist, additional vapor samples were taken without mist injection to determine the amount of evaporation from mist-loaded collector components. The average vapor concentration measured for all samples taken when oil mist was introduced to the system was 4.02 mg/m^3, or 8.8% of all oil introduced. Vapor concentrations caused by evaporation from collector components declined from 3-5 mg/m^3 as clean air initially passed through freshly loaded components to 1-2 mg/m^3 after air had passed through the components for about 12 hours. These findings suggest that even if a collector is 100% efficient for droplets of all diameters, some of the incoming mass will penetrate through the collector as vapor, and that evaporation of liquid oil retained on the collector itself can cause significant concentrations of vapor even if the collector has not been exposed to oil mist recently.

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INTRODUCTION

Mineral oil is used in machining and grinding processes to lubricate contact surfaces, to dissipate heat, and to remove ground material from the contact site. Application of mineral oil during the machining process results in the generation of mineral oil mist. This mist is generated by the splashing of the oil on the work piece and by the mechanical action of the machining tools.

Aerosolized mineral oil may contribute to the development of asthma, dermatitis, and lipid pneumonia.[2,3,6,12] In addition, recent epidemiological evidence has shown significant and cumulative exposure-related associations between cancers of the digestive tract and exposure to mineral oils.[2,12] As over 1 million workers in the United States are potentially exposed to mineral oil,[8] adequate control of mineral oil mist is needed.

Ideally, proper ventilation would transport the oil mist from the generation site to an air pollution control device, which would remove the droplets from the airstream. The clean air could then be re-circulated safely to the workroom. The mineral oil mist, however, may evaporate before reaching the collector. [11] The resulting oil vapor would pass through the collector. If the mist is captured by the collector, it may evaporate by the continual passage of air through the collector's filters. [5,10] Either way, some mist that enters the collection system would pass through the collector as vapor, even if the collector removes all droplets in the airstream.

The amount of evaporation depends on the plant temperature, the composition of the oil, the size distribution of the oil droplets, the collector design, the degree of saturation of the airstream with organic vapors, and other factors. The purpose of this paper is to examine the importance of evaporation in a mass balance for oil mist introduced to a mist collection system, and to investigate the rate at which collected oil evaporates from collector components.

METHODS

The work presented here consisted of two experiments: a mass balance experiment and an evaporation rate experiment. The goals of the mass balance experiment were to determine vapor concentrations in the duct under conditions that, as far as possible, replicated actual plant conditions and to quantify evaporation from individual collector components. The goal of the evaporation rate experiment was to determine how quickly oil would evaporate from a loaded filter as clean air passed through the filter. This section briefly describes the experimental set-up, the experimental techniques, and, finally, the experiments themselves.

Experimental Set-Up

Figure 1 shows the test set-up. Room air was drawn through a HEPA filter at the rate of 1700 m^3/hr (1000 cfm) into a round duct of diameter D=20 cm (8 in). After traveling 6 D through straight duct, the air passed through a calibrated 15 cm (6 in) orifice meter that monitored flow. The air then traveled 15 D through straight duct to enter a collector that had housing dimensions of 76 cm (30 in) wide, 67 cm (26.5 in) deep, and 2.67 m (8.75 ft) high. An air-locked, U-tube allowed fluid to drain from the collector.

Air that entered the collector turned vertically upward and passed through three filters in series. The first filter, a coalescing filter with dimensions 60 cm (23.5 in) x 60 cm (23.5 in) x 9.5 cm (3.75 in), contained two collection layers of 1.3 cm (0.5 in) thick foam pads sandwiched by corrugated wire screens. The second filter consisted of ten pockets in parallel. Each pocket was 67 cm (26.5 in) x 90 cm (35.5 in) x 0.16 cm (0.06 in) thick

when compressed for a total filter collection area of 12.1 m^2 (130.7 ft^2) and was composed of glass fibers with an average diameter of 3.1 μm. The third filter was a 95% DOP filter with 77 pleats. Each pleat was 56 cm (22 in) x 20 cm (8 in) for a total filter collection area of 17.5 m^2 (188 ft^2) and was composed of glass fibers with average diameter of 3.1 μm.

After passing through the filters, air flowed out the collector into a 20 cm (8 in) diameter, 90^0 elbow with a radius of curvature of 2.75 D. After the elbow, the air traveled 12 D through straight duct before making another 90^0 turn past a sampling probe toward the fan.

Fluids

A mineral oil may contain hundreds of compounds [4] so that a precise gas chromatography- mass spectroscopy (GC-MS) analysis of its components is impractical. Therefore, one experimental test fluid used in this work was a specially prepared mixture of straight-chained alkanes. This mixture was used because alkanes represent a majority of the mass in a typical mineral oil [4] and because the mixture would have known components easily quantified in a GC-MS analysis. The alkane mixture was composed 11% by mass of tetradecane, $C_{14}H_{30}$; 36% hexadecane, $C_{16}H_{34}$; 42% octadecane, $C_{18}H_{38}$; and 11% eicosane, $C_{20}H_{42}$. This mixture was chosen to mimic the vapor pressure characteristics of a commercial mineral oil, so that the alkane mixture would experience similar rates of evaporation to the commercial mineral oil. Additional tests were run with

a commercial mineral oil (Metal Lubricants Co., Harvey, IL) in the same experimental set-up to check that the two compounds behaved similarly.

Droplet Efficiency Measurements

Efficiency tests were run to determine the fraction of liquid droplets caught by the collector as a function of droplet size. [10] Collector efficiency can be determined from the number concentration of droplets in the airstream incident to the collector, C_1, and also the number concentration of droplets in the airstream leaving the collector, C_2. Efficiency, η, is then:

$$\eta = 1 - \frac{C_2}{C_1} \qquad (1)$$

A HEART nebulizer (B&B Medical Technologies, Orangevale, CA), introduced approximately 10 mg/m^3 of polydisperse alkane aerosol into the duct. To obtain droplet concentrations C_1 and C_2, the mist was introduced alternately at points upstream and downstream of the collector, see Figure 1. Position 1, the inlet position from which C_1 was obtained, was located at the start of the 90^0 elbow at the exit from the collector. Position 2, from which C_2 was obtained, was located in the straight duct 9 D upstream from the collector entrance. Droplets produced by the HEART nebulizer were counted five times, three times with the nebulizer at Position 2 and two times at Position 1. To ensure that any count differences observed between the positions were not caused by subtle shifts in the mist generation rate, the nebulizer was alternated between the positions

in a 2-1-2-1-2 pattern. The nebulizer continued to operate as it was moved between positions.

Droplets generated at the two positions were counted at a single location further downstream. The air stream was sampled through a probe designed to achieve a sampling efficiency of 100% for droplets less than 10 μm in diameter. [9] The probe was centered axially in the duct and its tip was located 2.25 D upstream from the start of the elbow. Velocity and concentration profiles measured across the duct at the sampling location were uniform so that droplet counts determined at the center of the duct were representative of the counts across the whole duct. [10] Droplets were measured and counted into 21 size intervals between 0.26 and 6.3 μm by an Aerosizer (Amherst Process Instruments Inc., Hadley, MA). The Aerosizer counts and size particles aerodynamically.

Vapor Measurements

A vacuum source was used to sample air in the duct just downstream from the 90^0 elbow leaving the collector, see Figure 1. The sampled air first passed through a glass fiber filter to remove any remaining aerosol that may have penetrated through the collector, then through an activated carbon tube to collect oil vapor, and finally through a calibrated rotameter to monitor flow, 2 L/min. Two vapor samples were taken simultaneously for 30 minutes, 180^0 apart on the circumference of the duct. After sampling, the carbon tubes were capped and stored at 4^0 C until GC-MS analysis. Daily background samples were taken at the entrance to the system, just downstream from the HEPA filter.

Carbon disulfide (CS_2) was used to extract the alkane vapor from the carbon tubes, according to a method described by NIOSH.[7] An internal standard technique was used to quantify the mass of each alkane collected on the tube; each alkane had its own internal standard with similar volatility. The samples were analyzed on a DB-5 60m x 0.32 mm id column (J & W Scientific, Folsom, CA) using an HP Series II Gas Chromatograph with an HP 5972 Mass Selective Detector (Hewlett Packard, Palo Alto, CA). The oven temperature was initially 60^0 C with a hold time of 0.2 min. Temperature was raised 15^0 C/min until 250^0 C, then raised 12^0 C/min until 300^0 C. Final hold time was five minutes. Injector temperature was 220^0 C.

To analyze the samples of vapor from the commercial mineral oil, several assumptions were necessary. Because the commercial mineral oil contained hundreds of compounds, many of which were unidentified, calibration curves could not be prepared for each. Instead, the mass of mineral oil vapor collected was tracked by ion 57, an ion common to nearly all compounds in the oil. The mass collected on the activated carbon was estimated by a calibration curve of ion 57 peak areas that resulted from known amounts of liquid mineral oil, with the assumption that equal masses of mineral oil liquid and vapor would give equal ion 57 areas. This technique will give inexact results if the components of the mineral oil in the vapor phase fractionate differently in the MS detector with respect to ion 57 than the components of the mineral oil in the liquid phase. As equal masses of different alkanes gave approximately equal ion 57 areas, this approach seemed reasonable.

For all vapor samples, each of the two replicate tubes was analyzed independently to limit effects of errors in sample preparation and in GC analysis. The two replicate tubes

were solvent extracted on different days, GC analyzed on different days, and used independent calibration curves for mass determination. The duct concentration was taken as the average of the values determined by the two replicate samples.

Experiments

Mass Balance Experiment

The mass balance experiment ran for eleven days. Four HEART nebulizers, collectively the "conditioning nebulizer", were used to introduce high concentrations (45-55 mg/m^3) of oil mist into the system at Position 2, see Figure 1. The nebulizer ran for approximately fifteen hours each day, with the other nine hours used for related tests. The conditioning nebulizer was weighed before and after use each day to determine the total mass of liquid nebulized into the system.

This nebulized liquid could have one of four fates: it could penetrate through the collector as liquid mist, it could collect on the filters and then drain from the collector as liquid, it could collect on the filters and then remain there as liquid, or it could evaporate. Tests were done each day to quantify these four mass flows. Collection efficiency measurements were run daily to determine how much aerosol penetrated through the collector. The oil that drained from the collector was weighed. Each filter was weighed to determine the amount of oil it retained. Vapor measurements were taken to determine the amount of evaporation in the system. Fluid samples were also taken each day from both the conditioning nebulizer and the drain for GC analysis. Determination of the composition of these samples allowed a mass balance for each alkane in the oil, with the

assumption that the oil retained on the filters was similar in composition to that which drained.

Mist efficiency tests using the alkane mix were run each of the first nine days of the mass balance experiment, as indicated by Table 1. Additional mist efficiency tests for the empty housing alone were run with commercial mineral oil and with oleic acid.

One goal of the mass balance vapor measurements was to determine the vapor concentration in the duct under conditions that, as far as possible, replicated actual plant conditions. On each test day, "mist-on" vapor samples were taken with the conditioning nebulizer running and all three collector filters in place; see Table 1 for the order of vapor tests taken during the mass balance experiment. The vapor concentration found from these 30 minute samples was assumed to represent the concentration in the system for that day. From this concentration and system air flow, the total percentage of nebulized fluid that left the collector in the vapor phase was calculated. Changes in these test results from day to day determined how vapor concentrations changed as the collector's filters became loaded with oil. To check the assumption that the alkane mix behaved like a commercial oil, "mist-on" samples were taken over the course of a separate, parallel experiment using commercial mineral oil as the test fluid.

Another goal of the mass balance vapor measurements was to quantify evaporation from individual collector components. Because the "mist-on" samples could not differentiate between vapor from mist that evaporated before reaching the collector and vapor from evaporation of droplets caught on the filters, additional vapor samples were

taken for 30 minutes each day while clean air passed through the system components with the mist generator turned off. These "clean-air" vapor samples determined the evaporation rate from the collector components into a clean airstream. Separate "clean-air" tests were run for the empty housing and for each filter placed individually in the housing. Because evaporation of oil from the housing could contribute to the amount of vapor in the system, and because the rate of evaporation from the housing could change with time, a "clean-air" sample was taken for the empty housing before and after each "clean-air" sample from a filter to distinguish between the housing and filter vapor contributions; Table 1 lists the order of vapor tests taken during the mass balance experiment. In addition, the collector components were weighed before and after each sample to determine mass loss. After the last housing sample, the "mist-on" sample described above was taken. On the last day of the mass balance experiment, a "clean-air" sample was also taken with all three filters in the collector.

Evaporation Rate Experiment

The goal of the evaporation rate experiments was to determine how quickly oil from a loaded filter would evaporate. The conditioning nebulizer was run continuously for two days with all components installed to load oil onto system components. Each of the filters was then removed and placed in a sealed plastic bag to limit evaporation. One by one, the filters were re-installed in the housing. A series of six "clean-air" vapor samples was then taken for each loaded filter to determine evaporation rates from each as a function of time Table 2 indicates sampling times for each of the six "clean-air" samples after room air was started through system components.

RESULTS

Mass Balance Experiment

Droplet Collection Efficiency

The collector with all filters installed removed virtually all oil mist droplets from the airstream. Both the coalescing and pocket filters had collection efficiencies below 100% for droplets smaller than about 1 μm. The 95% DOP filter, however, removed approximately 99.98% of oil droplets for all droplet diameters above about 0.5 μm. Data for droplets less than 0.5 μm were inconclusive as the Aerosizer is inefficient at counting droplets in this size range. The filter collection efficiency for the 95% DOP filter did not change as oil was loaded onto the filter.

Figure 2 shows the efficiency of the housing alone against droplet diameter for the alkane mix, mineral oil, and oleic acid. Error bars represent 95% confidence intervals for each data point.

Vapor Analyses

The average alkane vapor concentration in the duct was 4.02 mg/m^3 for all "mist-on" vapor samples taken from days 1-9 of the mass balance experiment. This concentration accounted for 8.8% of the nebulized alkane oil. Daily vapor concentrations did not change in a statistically significant manner as the filters became loaded with oil ($p= 0.12$). Figure 3 shows the average mass fraction for each alkane in the vapor phase. The vapor

samples contained much more tetradecane and hexadecane and much less octadecane and eicosane than the nebulized oil; the eicosane vapor concentrations were near zero.

Figure 4 shows individual alkane concentrations in the vapor phase for the days 1-9 "mist-on" vapor samples. Tetradecane concentrations were more variable than the concentrations of other alkanes. Figure 5 plots the vapor pressure of water in the duct, taken from relative humidity readings, versus tetradecane concentration. The relative humidity ranged from 35% to 64% during the daily "mist-on" vapor samples. Figure 5 shows that when water vapor pressures were high, tetradecane concentrations were high as well; this trend was significant ($p < 0.001$).

The average concentration of mineral oil vapor was 4.37 mg/m^3 for all "mist-on" vapor samples taken using commercial mineral oil as the test fluid. This concentration accounted for 11.0% of the nebulized commercial mineral oil. Daily duct concentrations did not change as a function of mass loaded onto the filters ($p = 0.21$).

Figure 6 shows the average vapor concentrations found during the "clean-air" vapor samples; it also shows the average vapor concentration of 3.68 mg/m^3 found during the "mist-on" vapor samples. Error bars represent one standard deviation for the averages. The figure has been plotted as a stack graph to show the contribution of the empty housing to each analysis. None of the filters caused a statistically significant increase in vapor concentration as it became loaded with oil over time ($p > 0.05$ for all).

During the thirty-minute "clean-air" vapor samples each day, the coalescing filter lost an average of 9.6 g, the pocket filter lost an average of 5.8 g, and the 95% DOP filter lost

an average of 5.4 g. None of these weight losses increased with mass of oil on the filter ($p > 0.05$ for all). During the "clean-air" vapor sample on day 11 with all three filters in the collector, the coalescing filter lost 22 g, the pocket filter lost 1 g, and the 95% DOP filter lost 1 g. Losses from the coalescing filter were due both to oil evaporation and drainage during the "clean-air" test; drainage was negligible for the pocket and 95% DOP filters.

Fluid Analyses

The average alkane mass fractions for the conditioning nebulizer and drain samples are shown in Figure 3. The drain samples contained slightly more octadecane and eicosane and slightly less tetradecane than the nebulized oil.

Overall Mass Balance

Table 3 shows results from the total mass balance and the individual alkane mass balances for the alkane mixture. This table lists the total mass of aerosol nebulized into the system for each alkane component. It also lists the mass recovered for each component from vapor, from liquid retained on the filters, from liquid drained from the collector, and from liquid mist that penetrated through the collector. Of the 14183 grams introduced into the system, 90.4% was recovered. Fluid drained from the collector represented 49.7% of nebulized oil. Fluid retained on the filters represented 31.8%. Vapor penetrating through the collector represented 8.8%. Thus, 9.6% of the oil was apparently missing due to either fluid left on collector walls or ventilation ducts or due to experimental error.

Evaporation Rate Experiment

Table 2 shows the vapor concentrations found during the evaporation rate experiments. Each component showed similar trends in evaporation rate; vapor concentrations were highest for the initial sample and were lowest for the final sample, with a general decrease in concentration in between. Figure 7 shows the alkane composition of the vapor that came from the pocket filter as a function of time. The most volatile components evaporated from the filter faster than the heavier compounds; the initial sample was nearly 50% tetradecane by mass, whereas the last sample was only about 5% tetradecane by mass. The vapor compositions from the housing, coalescing, and 95% DOP vapor samples also showed a shift towards heavier components as time progressed.

DISCUSSION

Evaporation

The results of the mass balance experiment are consistent with the idea that mineral oil components can evaporate. Table 3 shows approximately 10% of the alkane mix introduced into the system ended up in the vapor phase downstream of the collector. Even during the "clean-air" tests of the mass balance experiment, when no mist was introduced to the system, oil evaporating from the collector housing and filters caused downstream vapor concentrations over 3 mg/m^3. As expected, the lighter fractions of the oil evaporated more than the heavier compounds. Figure 3 shows that the vapor phase of the alkane mix was much lighter than the mix for the nebulized fluid, as it consisted almost entirely of tetradecane and hexadecane. The fluid drained from the collector was slightly heavier than the fluid introduced into the system, consistent with the idea that some of the lighter compounds evaporated from the nebulized fluid.

Results from the evaporation rate experiments show that vapor concentrations resulting from evaporation of collected mist from individual collector components can remain above 1 mg/m^3 for at least 13 hours after filter loading. For example, Table 2 shows that the vapor concentration due to evaporation from the pocket filter alone placed in the housing was 1.71 mg/m^3 even after clean air passed through the filter for 13 hours. This concentration probably would have been even higher if either or both of the other two filters had been in place. Thus, the collector generated significant concentrations of vapor even when it had not been exposed to oil mist recently.

A possible confounding effect with oil evaporation may be the concentration of water vapor in the air stream. Figure 4 shows that the tetradecane vapor concentrations varied greatly during the "mist-on" experiments, and Figure 5 shows that these concentrations were significantly correlated to water vapor concentrations. Perhaps water vapor competed with alkane vapors for adsorption sites on the collector's filters. Tetradecane, the most volatile of components in the fluid, may have been displaced into the airstream more easily than the heavier alkanes when humidities were high.

Vapor Saturation

The vapor measurement results suggest that saturation may have occurred for vapor concentrations downstream of the collector. Vapor concentrations measured when running clean air through any of the mist-loaded filters individually were comparable to vapor concentrations with the mist on and all three filters in place, as shown in Figure 6. This result could occur as a consequence of saturation.

Evaporation rates from the filters seemed to be limited as well. For the "clean-air" tests, vapor concentrations did not vary with the amount of oil present on the filters. This finding agrees with the observation that the rate of filter weight loss did not change as a function of oil mass present on the filters. Further evidence to support the idea that vapor concentrations approached saturation comes from the last "clean-air" vapor sample with all three filters in the collector. Both the pocket and the 95% DOP filters lost much less mass when all three filters were in place, only one gram each, than when they were placed in the collector individually, typically five to six grams. This implies oil evaporating from

the first-stage coalescing filter possibly saturated the air and prevented oil from evaporating from the pocket and 95% DOP filters that followed.

To check the assumption that the duct air was saturated, Raoult's Law was used to estimate the saturation vapor pressure for the alkane mixture. Raoult's Law relates the vapor pressure of fluid component i, p_i, to its mole fraction, χ_i, and saturation vapor pressure, $p_{sat,i}$, where

$$p_i = \chi_i \cdot p_{sat,i} \qquad (2)$$

Raoult's Law predicts a saturation vapor concentration of 13.59 mg/m^3 for vapor in equilibrium with fluid drained from the collector, composed of 9.37 mg/m^3 by tetradecane, 3.79 mg/m^3 by hexadecane, 0.41 mg/m^3 by octadecane, and 0.009 mg/m^3 by eicosane. These values would suggest that the airstream is not saturated as measured concentrations were less than theoretical concentrations for each alkane. Figure 4 shows the average measured "mist-on" vapor concentration of 4.02 mg/m^3, composed of 1.43 mg/m^3 by tetradecane, 2.33 mg/m^3 by hexadecane, 0.26 mg/m^3 by octadecane, and 0.007 mg/m^3 by eicosane.

Some deviation of measured concentrations from theoretical concentrations predicted by Raoult's Law should be expected as fluid draining from the collector may not be representative of the droplets evaporating in the system. Large droplets draining from the collector should comprise the majority of the mass recovered from the drain; so this drained fluid should have a similar compositon as the large droplets. Evaporation, however, should mostly be occurring from small droplets. If most of the evaporation in

system is coming from the small droplets, the theoretical saturation vapor pressure should be based on equilibrium with the mole fractions for these small droplets and not with the mole fractions for the drained liquid. Since the lighter alkanes should evaporate more than the heavier alkanes, the small droplets should have reduced mole fractions for the lighter alkanes and increased mole fractions for the heavier alkanes. This reduction of mole fraction for tetradecane in the small droplets may partially explain why the measured concentration of tetradecane vapor is nearly an order of magnitude less than the theoretical concentration of tetradecane vapor based on equilibrium with the drained liquid, whereas the other less-volatile alkanes are closer to expected results. As mentioned above, another possible confounding effect for tetradecane concentrations is the amount of water vapor in the system.

Missing Mass

The mass balance was not closed in that 9.6%, or 1053 ml, of the nebulized oil was missing. A likely explanation for this missing oil is that it remained undrained on the walls of the collector. If the missing oil were evenly distributed over the interior surface of the collector housing, it would result in an oil film 0.12 mm deep. Since significant evaporation from the housing alone occurred, this hypothesis seems reasonable. Visible traces of oil also were found on the inside of the upstream ductwork after the experiment.

Another possible explanation for the missing 9.6% mass is error in vapor sampling techniques. Some of the alkane vapor may have collected on the walls of the sampling train or on the glass fiber filter.[1] To limit these losses, the sampling lines were as short as

possible. Tests run with dodecane, $C_{12}H_{26}$, suggested that no sampling losses occurred through the sampling line or glass fiber filter for this compound. Tests with the commercial mineral oil, however, indicate that losses of about 15 % of the total vapor sampled may be possible in the sampling train, with larger losses for the heavier oil components. Errors due to line losses would cause the vapor concentrations reported here to be underestimated.

Alkane Oil vs Commercial Mineral Oil

The results from the droplet efficiency tests and from the "mist-on" vapor samples suggest that the alkane oil and the commercial mineral oil behave similarly. Figure 2 shows the collection efficiency for the empty housing alone for the alkane oil, mineral oil, and oleic acid. Collection efficiency for droplets should approach zero as droplet diameter approaches zero. This behavior was seen for the non-volatile oleic acid; it has a very low vapor pressure and so is less likely to evaporate than the lighter components of the other fluids. However, collection efficiencies did not approach zero for small droplets for either the alkane or mineral oils, due to partial evaporation of the droplets as they passed through the empty housing. Evaporation would cause the collector to appear to have removed the droplets. The mineral oil and alkane oil had similar "removal" efficiencies so that the two fluids should have similar rates of evaporation. Because the apparent efficiency for small droplets was slightly greater for mineral oil than for the alkane oil, slightly more mineral oil should evaporate than alkane oil. This result agrees with experimental data that showed an average concentration of 4.37 mg/m^3 for

commercial mineral oil vapor and an average concentration of 4.02 mg/m^3 for alkane oil vapor downstream of the collector.

CONCLUSIONS

Because the alkane and mineral oils used in this experiment had low vapor pressures under room conditions, they would not normally be thought to evaporate. However, the surface area for oil mists in aerosol form, or for oil droplets spread over the collection area of a filter, is so great that the aggregate evaporation was appreciable.

Vapor concentration measurements indicated approximately 10% of a mineral oil introduced as liquid mist into a collector- ventilation system had become vapor downstream of the collector. Thus, even if a collector is 100% efficient for droplets of all diameters, some of the incoming oil will penetrate the collector as vapor. If the outlet air is re-circulated into the plant, the vapor may recondense; if the outlet air is discharged outdoors, the vapor can be a source of volatile organic compound (VOC) emissions.

Vapor concentrations of approximately 4 mg/m^3 were measured during tests that, as far as possible, replicated operational conditions in a plant. The mass flow of mist droplets penetrating the collector was very low, so that the concentration of the oil in the vapor phase downstream of the collector was more than an order of magnitude greater than the concentration in the droplet phase. Vapor concentrations of approximately 4 mg/m^3 were also measured during tests that passed clean air through collector components loaded with oil, indicating that the collector loaded with oil droplets can generate significant concentrations of vapor even if no mist has entered the collector recently.

The lighter components of the oil evaporated more readily than the heavier components. Thus, the vapor contained a larger mass fraction of the lighter components

and a smaller mass fraction of the heavier components than were present in the liquid droplets introduced to the system.

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Table 1. Mass balance experiments, days 1-11: the table lists the experiments performed each day

	DAY										
TESTS	1	2	3	4	5	6	7	8	9	10	11
Efficiency											
Housing	X	X	X	X	X	X	X	X	X		
Housing + Coalescing	X	X	X	X	X	X	X	X	X		
Housing + Pocket	X	X	X	X	X	X	X	X	X		
Housing + 95% DOP	X	X	X	X	X	X	X	X	X		
"Mist-On" Vapor	X	X	X	X	X	X	X	X	X		
"Clean-Air" Vapor											
Housing 1		X	X	X	X	X	X	X	X		X
Housing + Coalescing		X	X	X	X	X	X	X	X		
Housing 2		X	X	X	X	X	X	X	X		
Housing + Pocket		X	X	X	X	X	X	X	X		
Housing 3		X	X	X	X	X	X	X	X		
Housing + 95% DOP		X	X	X	X	X	X	X	X		
Housing 4		X	X	X	X	X	X	X	X		
Housing + All Filters											X

Table 2. Evaporation rate experiments: vapor sampling times and results. The tabulated values are vapor concentrations in mg/m^3.

Sample time (min*)	Empty Housing	Coalescing	Pocket	95% DOP
0-30	2.38	3.16	5.16	4.96
30-60	1.56	3.05	4.77	2.89
60-90	1.52	2.94	5.04	3.03
90-150	1.05	2.52	4.21	2.59
150-210	1.00	2.85	3.25	2.67
overnight, ~ 780	0.31	1.24	1.71	0.77

* Indicates time after clean air was started through system components

Table 3. Mass balance for alkane fluid introduced during days 1-11.

	c14(g)	c16(g)	c18(g)	c20(g)	total(g)
NEBULIZED	1633	5221	5903	1426	14183
Vapor	454	710	82	2	1247
Liquid Retained on Filters					
Coalescing	165	750	921	220	2056
Pocket	180	816	1002	240	2238
95% DOP	18	83	102	25	228
Total	363	1649	2025	485	4522
Drain	567	2568	3157	755	7047
Droplet Penetration	~ 0	~ 0	~ 0	~ 0	~ 0
RECOVERED	1383	4927	5264	1242	12816
% Recovered	84.8	94.4	89.2	87.1	90.4

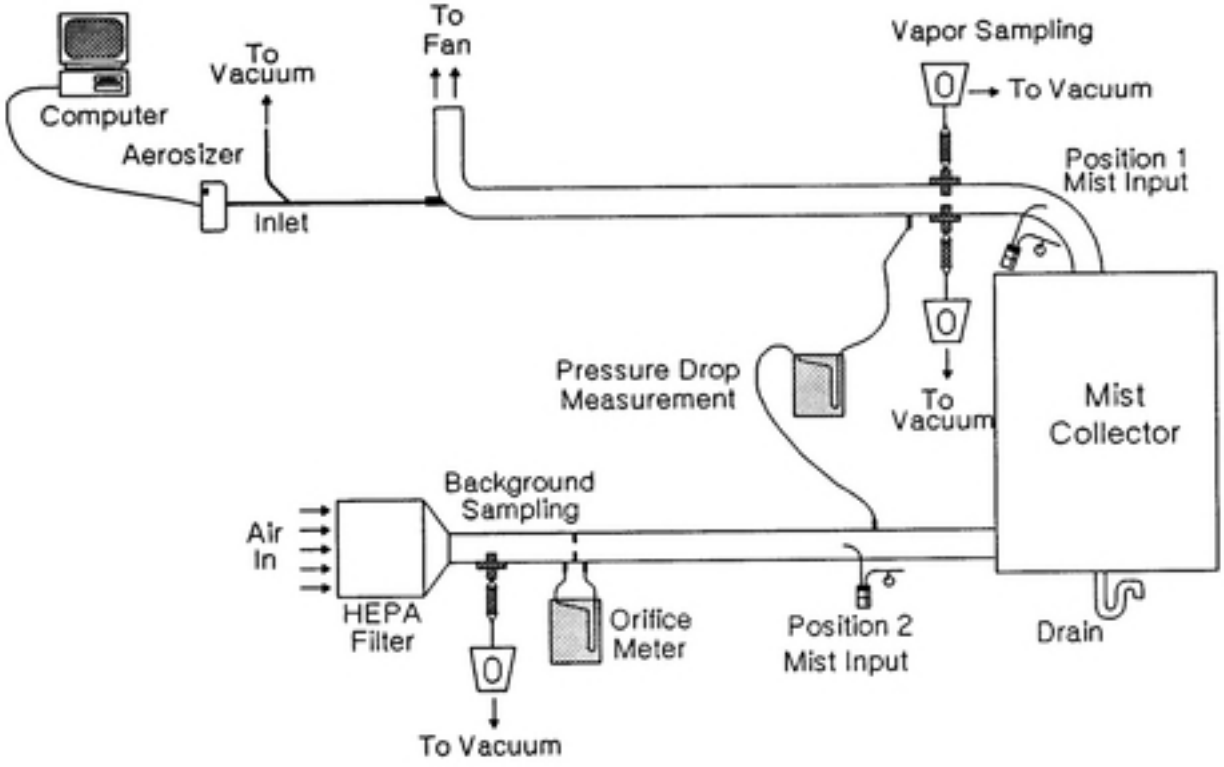

Figure 1. Schematic diagram of experimental set-up.

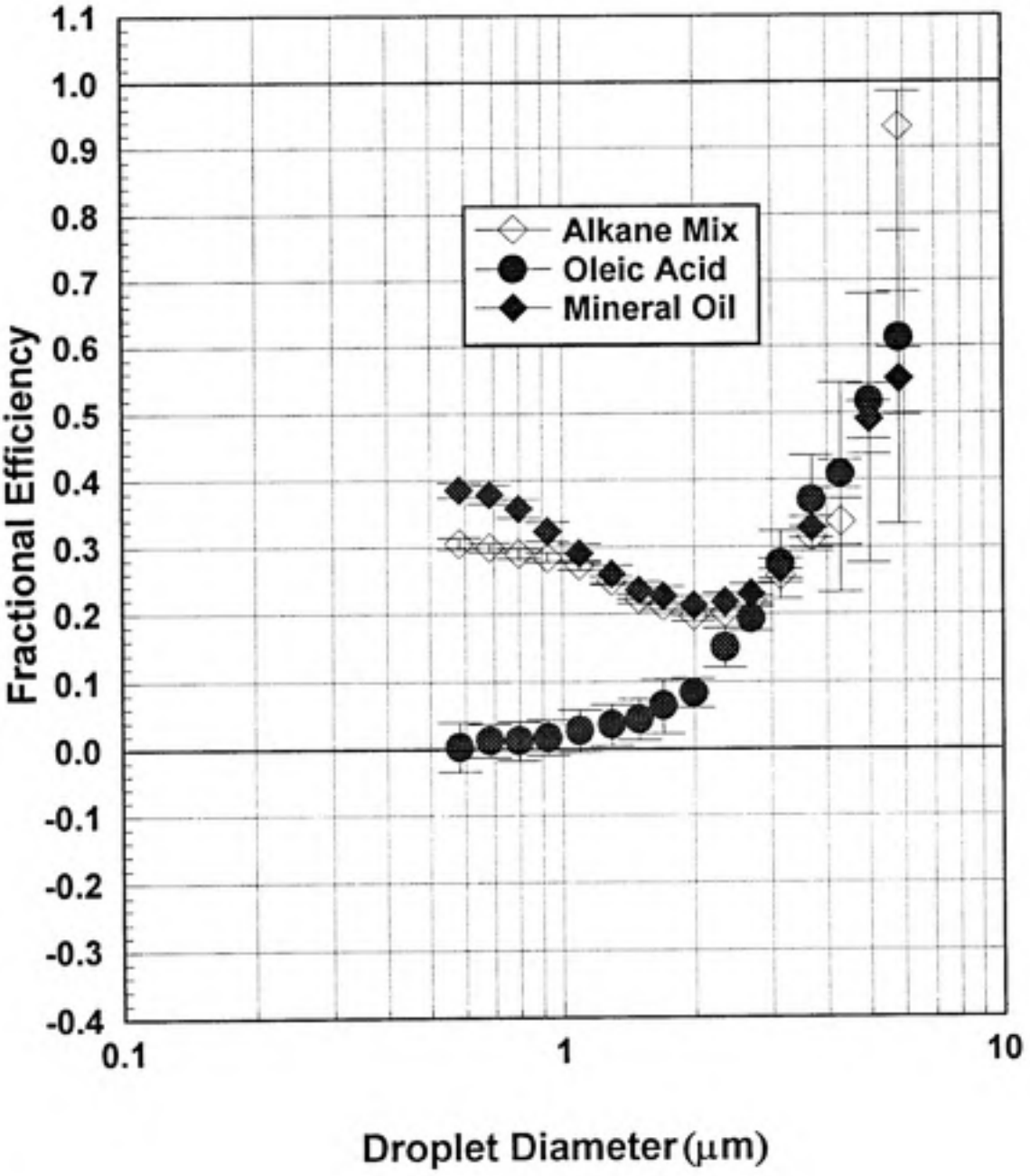

Figure 2. Fractional efficiency of housing versus droplet diameter for mineral oil, alkane oil, and oleic acid mists. Error bars represent 95% confidence intervals.

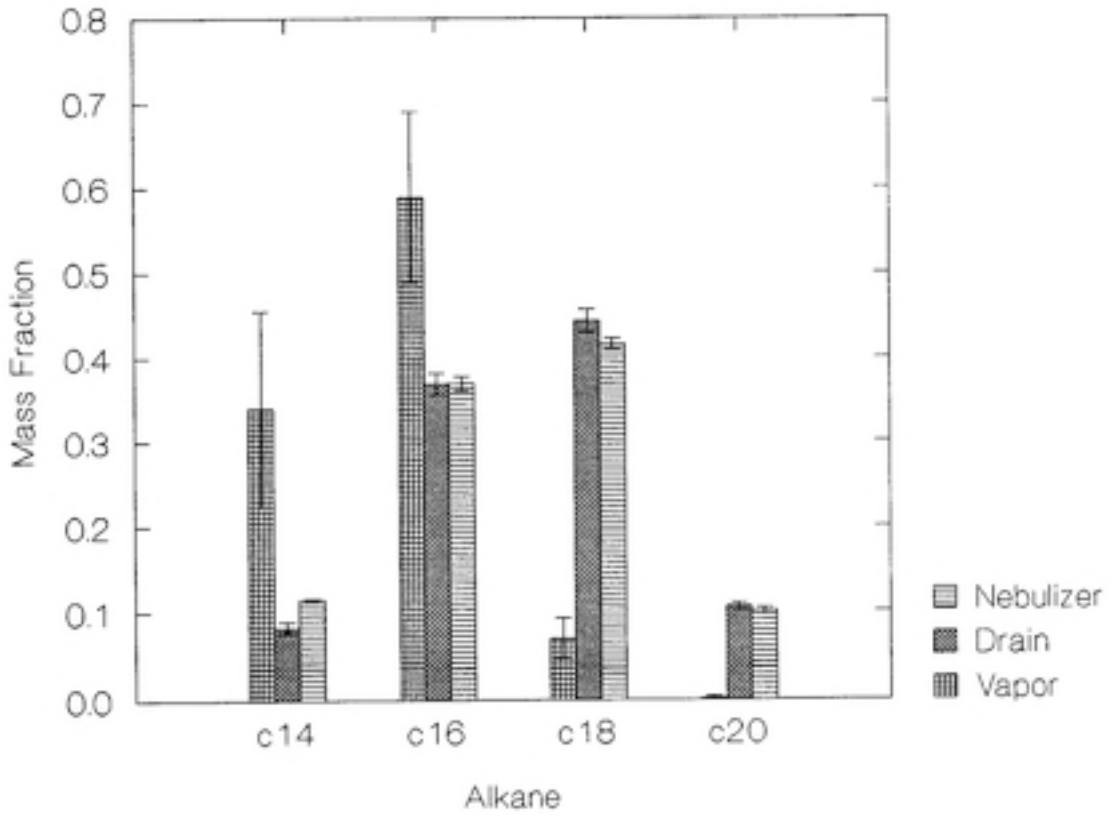

Figure 3. Average alkane mass fractions of drain, nebulizer, and vapor samples taken during mass balance tests, days 1-11. Error bars represent one standard deviation of the averages.

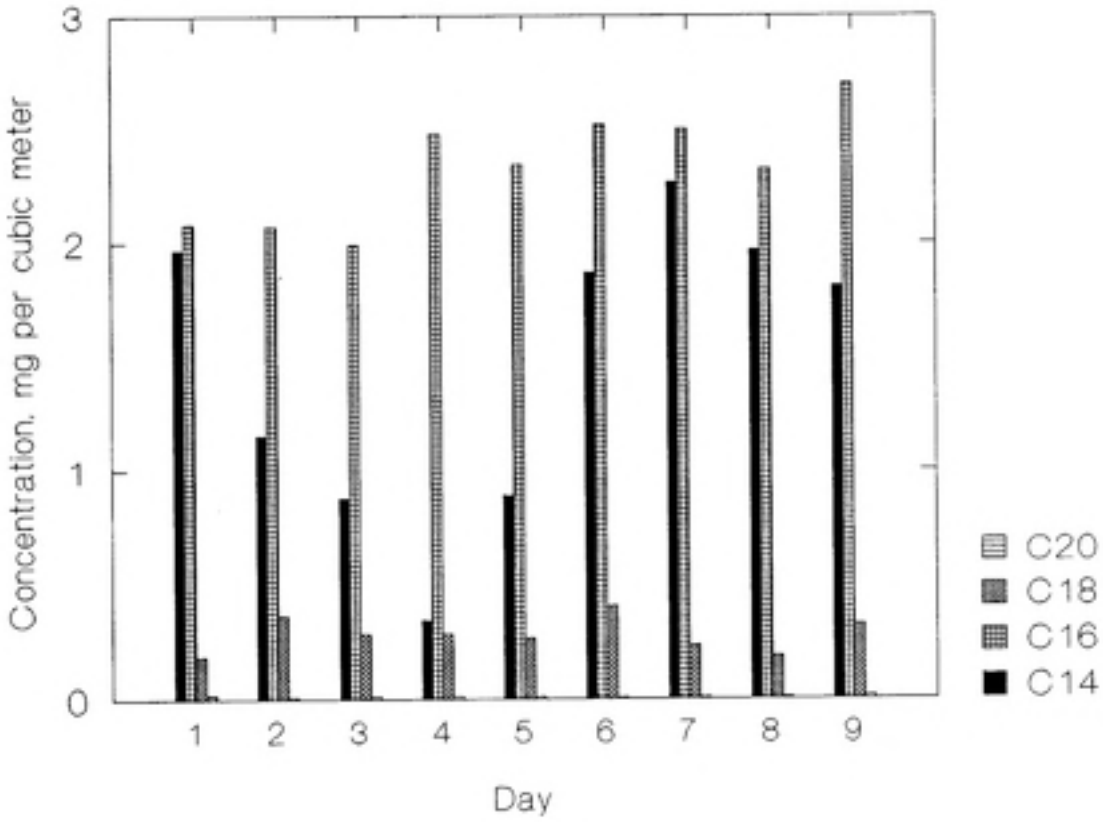

Figure 4. Daily alkane vapor concentrations measured as high concentrations of mist (45-55 mg/m^3) were injected into the airstream upstream of the collector with all three filters in place, days 1-9.

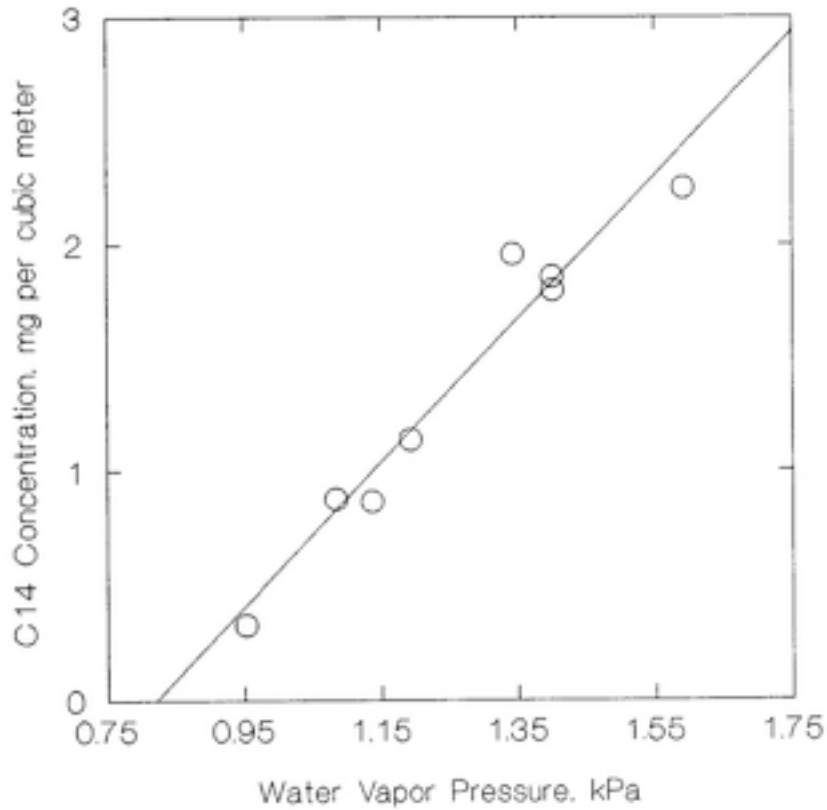

Figure 5. Water vapor pressure versus measured tetradecane vapor concentration as high concentrations of mist were injected into the air upstream of the collector with all three filters in place, days 1-9.

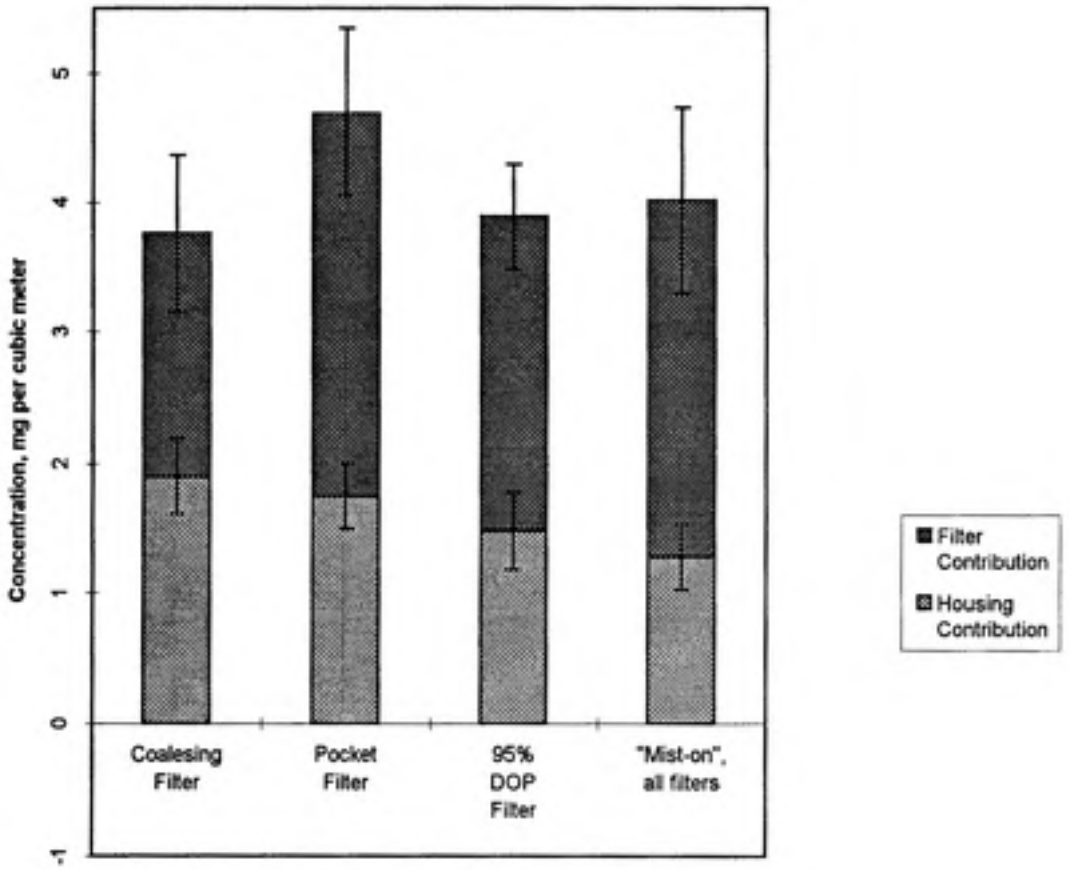

Figure 6. Average vapor concentrations measured during mass balance experiment. Coalescing, pocket, and 95% DOP values represent average concentrations measured as clean air, without injected mist, passed through each. "Mist-on" values represent average concentrations measured as high concentrations of mist were injected upstream of the collector with all three stages in place. Concentrations are broken down to show the contribution of the empty housing to each reported value. Error bars represent one standard deviation of the averages.

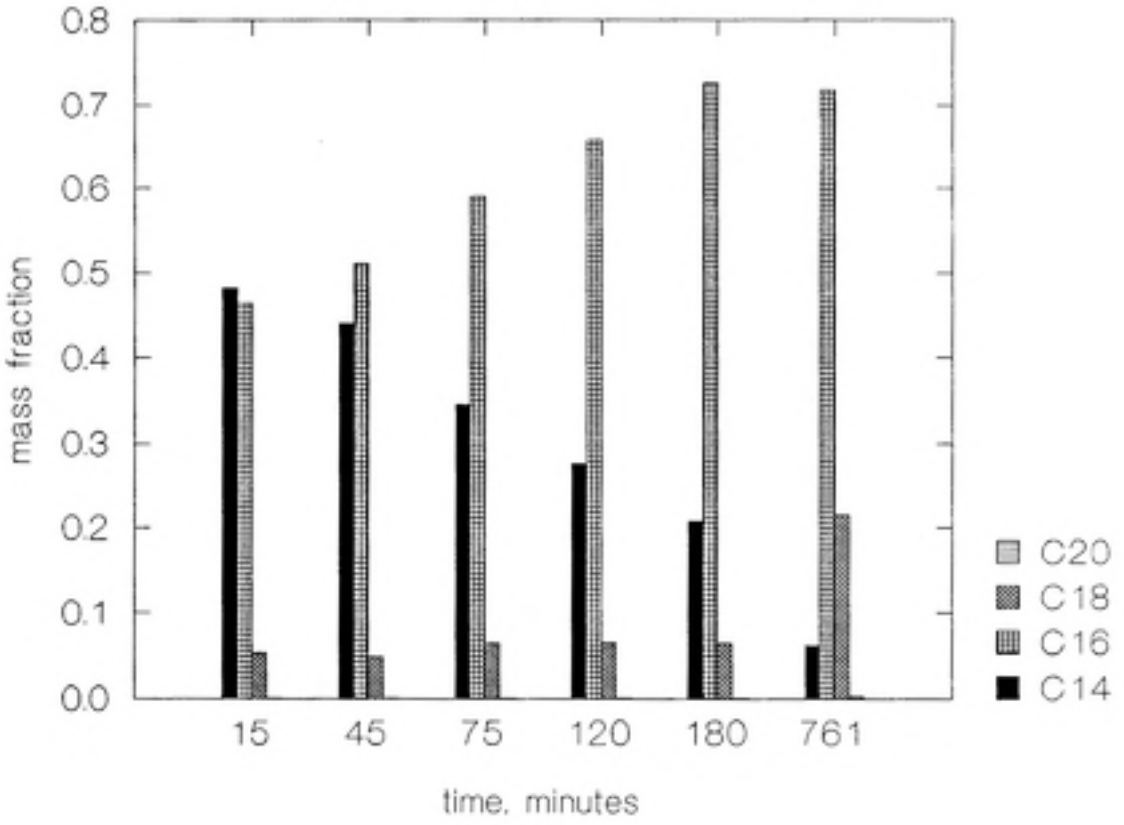

Figure 7. Composition of vapor as a function of time measured while clean air, without injected mist, passed through the pocket filter. Times indicate minutes after clean air was started through the filter.

Appendix A

Standard Operating Procedure

STANDARD OPERATING PROCEDURE

Efficiency Measurements

1.0 Preparing Equipment

1.1 Preparing Aerosizer

1.1.1 Turn on the NEC PowerMate SX/20i computer and the API Aerosizer. Allow the Aerosizer to warm up for at least 1 hour.

1.1.2 Set the Aerosizer flow to 2.5 L/min. Set run length to 1 minute. Set the density for the mineral oil to 0.77 g/cm^3.

1.1.3 Set the bypass flow to 7.4 cfh.

1.2 Preparing HEART Nebulizer

1.2.1 Ensure that the HEART nebulizer is clean.

1.2.2 Fill the HEART nebulizer to one-half way full.

2.0 Making an Efficiency Test

2.1 Preparing for Efficiency Test

2.1.1 Turn on system airflow and adjust damper in duct until a pressure of 2.45 in. H_2O.

2.1.2 Attach the HEART nebulizer to the mist inlet at Position 2. Attach the nebulizer to the compressed air source. Turn on the compressed air flow to 11 cfh. Allow the nebulizer to stabilize for a minimum of five minutes. Record the compressed air flow.

2.1.3 Record the subdirectory in which the count data will be stored.

2.1.4 Record time, temperature, and relative humidity.

2.2 Running an Efficiency Test

2.2.1 Record the sample details on the computer. After the HEART nebulizer has stabilized, make a measurement with the Aerosizer. Record the run

number for the measurement.

2.2.2 Detach the HEART nebulizer from the mist inlet. Attach the nebulizer to the mist inlet at Position 1.

2.2.3 Repeat 2.2.1

2.2.4 Detach the HEART nebulizer from the mist inlet. Attach the nebulizer to the mist inlet at Position 2.

2.2.5 Repeat 2.2.1

2.2.6 Repeat 2.2.2

2.2.7 Repeat 2.2.1

2.2.8 Repeat 2.2.4

2.2.9 Repeat 2.2.1

2.2.10 Turn off the compressed air to the HEART nebulizer. Detach the nebulizer from the mist inlet and the compressed air source.

Starting a Conditioning Cycle

1.0 Preparing Conditioning Nebulizer

1.1 Ensure that the conditioning nebulizer is clean.

1.2 Fill the conditioning nebulizer up to the "filled" line with oil.

1.3 Weigh and record the mass of the filled conditioning nebulizer with the Mettler PM34-K.

2.0 Taking Mass Balance Measurements

2.1 Use pipet to take 1 ml of oil from each tub of the conditioning nebulizer. Mix both samples into the same autosampler vial.

2.2 Cap vial and place it in refrigerator.

2.3 Weigh and record mass of empty bucket to be placed under drain with the Mettler PM34-K. Place the bucket under the drain.

2.4 Weigh and record mass of each collector filter with the Mettler PM34-K. Place each filter in the collector.

3.0 Operating Conditioning Nebulizer

3.1 Attach nebulizer to mist inlet. Attach nebulizer to compressed air source.

3.2 Turn on air flow and adjust damper in duct until a pressure drop across the orifice plate is 2.45 in. H_2O.

3.3 Turn on the compressed air source to 56 cfh.

3.4 Record pressure drop across orifice plate, pressure drop across collector, temperature, relative humidity, atmospheric pressure, and nebulizer flow.

Vapor Sampling

1.0 Taking "Mist-on" Vapor Samples

1.1 Preparing the conditioning nebulizer

1.1.1 Inspect the conditioning nebulizer to ensure that it is clean.

1.1.2 Fill the conditioning nebulizer up to the "filled" line with oil.

1.1.3 Weigh and record mass of the filled conditioning nebulizer with the Mettler PM34-K.

1.2 Preparing the sampling train

1.2.1 Clean filter casing and its tygon tubing connectors with methyl alcohol and distilled water. Air dry casings and connectors.

1.2.2 Weigh and record mass of glass fiber filter and ring holder with the Mettler AE 200 and place them into cleaned filter casing.

1.2.3 Score carbon tube. Insert tube into the filter casing's tygon tube connector.

1.2.4 Adjust flow through sampling lines to about 2.3 L/min.

1.2.5 Insert filter casing into ductwork, making sure that casing fits snugly against sampling hole (use tape around casing, if necessary). Place duct

tape around where the casing rests against the outside of the duct to prevent air leaks.

1.3 Taking Vapor Sample

1.3.1 Attach conditioning nebulizer to mist inlet at position 2. Attach the nebulizer to the compressed air source

1.3.2 Turn on air flow and adjust damper in duct until the pressure drop across the orifice plate is 2.45 in. H_2O. Record pressure drop.

1.3.3 Connect sampling line to carbon tube connected to filter casing.

1.3.4 Turn on compressed air source to conditioning nebulizer to 56 cfh.

1.3.5 Record time, temperature, relative humidity, atmospheric pressure, pressure drop across collector, pressure drop from atmosphere to the sampling location, nebulizer flow, and sampling flow.

1.3.6 Sample for 30 minutes.

1.3.7 After 30 minutes, disconnect compressed air source from nebulizer. Disconnect sampling line from carbon tube. Remove nebulizer and replace stopper in mist inlet. Remove filter casing from the duct and place duct tape over sampling hole.

1.3.8 Cap carbon tubes and place in refrigerator.

1.3.9 Weigh and record mass of glass fiber filters and ring holders with the Mettler AE 200. Weigh and record mass of the conditioning nebulizer on the Mettler PM34-K.

1.3.10 Repeat 1.2.1

2.0 Taking "Clean-Air" Vapor Samples

2.1 Weigh filter used in "clean-air" sample on Mettler PM34-K. Place filter in collector.

2.2 Preparing vapor sampling train

2.2.1 Repeat 1.2.1

2.2.2 Repeat 1.2.2

2.2.3 Repeat 1.2.3

2.2.4 Repeat 1.2.4

2.2.5 Repeat 1.2.5

2.3 Taking vapor sample

2.3.3 Repeat 1.3.2

2.3.4 Repeat 1.3.3

2.3.5 Record time, temperature, relative humidity, atmospheric pressure, pressure drop across collector, pressure drop from atmosphere to sampling line, and sampling line flow

2.3.6 After 30 minutes, disconnect carbon tube from sampling line. Remove filter casings from duct and place tape over sampling holes.

2.3.7 Weigh and record mass of glass fiber filter and ring holder with Mettler AE 200.

2.3.8 Repeat 1.2.1

2.4 Remove filter from collector and weigh on Mettler PM34-K.

Ending a Conditioning Cycle

1.0 Stopping the Conditioning Nebulizer

1.1 Turn off the compressed flow to the conditioning nebulizer. Detach the conditioning nebulizer from the mist inlet. Place stopper in mist inlet.

1.2 Turn off air flow.

1.3 Weigh and record the mass of the conditioning nebulizer on the Mettler PM34-K.

2.0 Taking Mass Balance Measurements

2.1 Use pipet to take 1 ml of oil from each tub of the conditioning nebulizer. Mix both samples into same autosampler vial. Cap vial and place it in refrigerator.

2.2 Remove filters from the collector. Weigh and record mass of each filter with the Mettler PM34-K.

2.3 Allow fluid to drain from the collector for at least 15 minutes after shutting down air flow.

2.4 After time for draining, weigh and record the mass of the filled drain bucket with the Mettler PM34-K.

2.5 Use pipet to take 1 ml of fluid from drain bucket. Place sample in autosampler vial. Cap vial and place in refrigerator.

2.6 Discard the drained oil into a hazardous waste container.

Carbon Tube Analysis

1.0 Calibrate Mettler AE 200 balance.

2.0 Preparing individual alkanes for calibration curves

2.1 Place 1 µl of carbon disulfide (CS_2) into autosampler vial.

2.2 Use syringe to inject approximately 10 µl of each tetradecane and hexadecane into CS_2 in vial.

2.3 Weigh out approximately 7.5 mg of each octadecane and eicosane on Mettler AE 200 and place into CS_2 in vial.

2.4 Cap vial.

3.0 Preparing internal standards for calibration curves

3.1 Repeat 2.1

3.2 Use syringe to inject approximately 4 µl of each deuterated tetradecane and deuterated hexadecane into CS_2 in vial.

3.3 Weigh out approximately 3.5 mg of each deuterated nonadecane and deuterated eicosane on Mettler AE 200 and place into CS_2 in vial.

3.4 Repeat 2.4

4.0 Prepare syringe spike solution for samples

4.1 Repeat 2.1

4.2 Use syringe to inject approximately 10 µl of dodecane into CS_2 in vial

4.3 Repeat 2.4

5.0 Prepare calibration curve samples

5.1 Score unused charcoal tube, remove cotton wick, and place charcoal from front collection section of tube into a 16 ml glass vial

5.2 Place 5 µl of alkane solution on charcoal in vial, place 4 µl of internal standard solution on charcoal in vial, place 2.045 ml of CS_2 on charcoal in vial

5.3 Cap vial and place parafilm around cap to limit evaporation.

5.4 Allow CS_2 to desorb vapor from charcoal for 30 minutes, gently agitating the vial every 10 minutes. Remove parafilm and cap from vial.

5.5 Extract 100 µl from CS_2-charcoal slurry and place into autosampler vial with insert.

5.6 Place 3 µl of syringe spike into insert.

5.7 Use crimper to cap autosampler vial.

5.8 Repeat 5.1-5.7 except use 15 µl alkane solution and 2.035 ml CS_2 in 5.2

5.9 Repeat 5.1-5.7 except use 25 µl alkane solution and 2.025 ml CS_2 in 5.2

5.10 Repeat 5.1-5.7 except use 50 µl alkane solution and 2.0 ml CS_2 in 5.2

6.0 Desorb a carbon tube vapor sample

6.1 Score charcoal tube sample, remove cotton wick, and place charcoal from front collection section of tube into 16 ml glass vial

6.2 Add 4 µl of internal standard solution and 2.05 ml of CS_2 to charcoal in vial

6.3 Repeat 5.3

6.4 Repeat 5.4

6.5 Repeat 5.5

6.6 Repeat 5.6

6.7 Repeat 5.7

7. Gas Chromotagraphy- Mass Spectrometry (GC-MS) Analysis

7.1 If necessary, change GC column to a DB-5 type

7.2 Check for GC air/water leaks and tune using Standard Spectra Autotune

7.3 Run sample on GC

7.3.1 Use oven temperature program with an initial temperature of 60^0 C with 0.2 min hold, followed by temperature increase of 15^0 C/min until 250^0 C, followed by a temperature increase of 12^0 C/min until 300^0 C with a final hold of 5 minutes

7.3.2 Use injector temperature of 220^0 C

7.3.3 Use detector temperature of 300^0 C

7.4 If running many samples, must make new calibration standards every 12 hours. Must tune the GC-MS daily.

Appendix B

Experimental Data

Table51 Count data for efficiency tests using silicone oil as test fluid

Collector		Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta
fluid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
rep		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
stage		Shell	Shell	Shell	Shell	Shell	S+S1	S+S1	S+S1	S+S1	S+S1	S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S	S	
position		2	1	3	1	2	2	1	2	1	2	2	1	2	1	3	2	1	2	1	2	2	1	
pr 5.833		247.1	424.1	340.1	306.1	189.1	326.1	368.1	304.1	457.1	349.1	78.1	356.1	87.1	466.1	78.1	0.1	516.1	3.1	452.1	0.1	313.1	421.1	
pr 4.884		1210.1	1950.1	1300.1	1700.1	1190.1	1140.1	1750.1	1310.1	1850.1	1290.1	264.1	1590.1	295.1	1750.1	299.1	7.1	2080.1	8.1	2073.1	12.1	1130.1	1680.1	
pr 4.290		2480.1	3480.1	2500.1	3550.1	2280.1	2480.1	3420.1	2480.1	3180.1	2430.1	606.1	3070.1	694.1	3210.1	679.1	14.1	3710.1	24.1	3600.1	16.1	2280.1	3430.1	
pr 3.888		1170.1	1110.1	1160.1	1230.1	1140.1	1050.1	1250.1	1320.1	1270.1	1180.1	231.1	1170.1	235.1	1170.1	254.1	11.1	1300.1	12.1	1300.1	3.1	1510.1	1080.1	
pr 3.142		1680.1	2280.1	1710.1	2300.1	1620.1	1640.1	2150.1	1740.1	2140.1	1810.1	343.1	2170.1	263.1	2120.1	292.1	10.1	2270.1	8.1	2250.1	10.1	1430.1	1790.1	
pr 2.683		27000.1	40300.1	27200.1	39500.1	29800.1	27000.1	37700.1	26500.1	37300.1	26000.1	2790.1	33900.1	2910.1	34300.1	3070.1	51.1	38500.1	48.1	38600.1	63.1	25100.1	34700.1	
pr 2.345		99100.1	135000.1	93400.1	134000.1	92700.1	91100.1	129000.1	91100.1	126000.1	89200.1	7950.1	114000.1	7950.1	115000.1	8120.1	174.1	131000.1	198.1	130000.1	170.1	87800.1	123000.1	
pr 1.990		109000.1	150000.1	106000.1	148000.1	105000.1	102000.1	141000.1	103000.1	140000.1	101000.1	8946.1	127000.1	8950.1	126000.1	9340.1	158.1	145000.1	188.1	144000.1	175.1	102000.1	140000.1	
pr 1.897		109000.1	151000.1	111000.1	156000.1	110000.1	105000.1	147000.1	106000.1	146000.1	104000.1	9070.1	132000.1	9260.1	134000.1	9320.1	169.1	151000.1	216.1	149000.1	172.1	105000.1	145000.1	
pr 1.497		130000.1	180000.1	130000.1	181000.1	130000.1	123000.1	169000.1	125000.1	173000.1	121000.1	4300.1	153000.1	4280.1	155000.1	4350.1	229.1	174000.1	247.1	172000.1	230.1	126000.1	170000.1	
pr 1.296		139000.1	146000.1	113000.1	147000.1	109000.1	102000.1	139000.1	102000.1	139000.1	100000.1	2400.1	125000.1	2390.1	127000.1	2400.1	191.1	140000.1	183.1	140000.1	158.1	107000.1	140000.1	
pr 1.095		77100.1	89900.1	77900.1	100000.1	77300.1	70700.1	94500.1	79600.1	95000.1	69100.1	1130.1	86500.1	1070.1	89900.1	1140.1	132.1	96800.1	126.1	95800.1	140.1	76700.1	96200.1	
pr 0.427		60500.1	77200.1	61000.1	77700.1	60800.1	53100.1	73400.1	53400.1	73500.1	52600.1	597.1	66900.1	583.1	67500.1	640.1	94.1	74300.1	131.1	74200.1	83.1	59800.1	73400.1	
pr 0.798		78600.1	96800.1	79000.1	97000.1	78400.1	63500.1	92100.1	62800.1	93100.1	61400.1	514.1	85700.1	508.1	85900.1	529.1	139.1	94200.1	118.1	94600.1	127.1	77400.1	93500.1	
pr 0.683		35600.1	44400.1	36800.1	44300.1	35400.1	29700.1	42700.1	29400.1	42500.1	29400.1	163.1	38900.1	132.1	39600.1	152.1	86.1	43100.1	94.1	43000.1	97.1	34400.1	42700.1	
pr 0.583		28500.1	35400.1	28600.1	35600.1	28200.1	23800.1	33900.1	23600.1	34400.1	23700.1	108.1	31600.1	99.1	32300.1	104.1	54.1	34900.1	41.1	35200.1	41.1	27500.1	34300.1	
pr 0.498		17400.1	22600.1	17400.1	22500.1	17000.1	14700.1	21700.1	15400.1	22000.1	15100.1	168.1	20400.1	31.1	20700.1	21.1	0.1	22700.1	32.1	22600.1	31.1	16800.1	21400.1	
pr 0.429		9490.1	11000.1	8160.1	11200.1	7760.1	917.1	10900.1	1170.1	11400.1	744.1	91.1	10400.1	4.1	10500.1	7.1	0.1	11400.1	16.1	11800.1	5.1	7760.1	11000.1	
pr 0.368		3060.1	3810.1	2800.1	3860.1	2310.1	157.1	3810.1	277.1	3720.1	1.1	0.1	3740.1	0.1	3890.1	1.1	0.1	4170.1	10.1	3870.1	3.1	3060.1	3770.1	
pr 0.314		1000.1	1580.1	1040.1	1700.1	494.1	0.1	1330.1	39.1	1510.1	0.1	0.1	1440.1	0.1	1470.1	0.1	16.1	1330.1	3.1	1590.1	0.1	803.1	1580.1	
pr 0.269		9.1	398.1	48.1	308.1	0.1	0.1	319.1	19.1	427.1	1.1	0.1	47.1	0.1	557.1	0.1	0.1	2.1	0.1	238.1	0.1	89.1	344.1	

Collector		Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta	Mon_3sta
fluid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
rep		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3
stage		S	S	S	S + S1	S + S1	S + S1	S + S1	S + S1	S + S2	S + S2	S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S	S	S
position		2	1	3	2	1	2	1	2	2	1	2	1	2	1	3	2	1	3	2	1	2	1	
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
pr 5.833		284.1	410.1	299.1	377.1	496.1	418.1	502.1	429.1	175.1	490.1	180.1	508.1	180.1	0.1	478.1	8.1	493.1	8.1	278.1	429.1	301.1	389.1	
pr 4.884		1010.1	1770.1	945.1	1540.1	2030.1	1570.1	1990.1	1500.1	718.1	2390.1	880.1	2200.1	840.1	0.1	2220.1	19.1	2410.1	20.1	1330.1	2020.1	1260.1	2080.1	
pr 4.290		2190.1	3520.1	2140.1	2950.1	3980.1	3020.1	3460.1	2770.1	1190.1	4370.1	1060.1	3940.1	1040.1	0.1	3940.1	17.1	4350.1	25.1	2470.1	3880.1	2350.1	3430.1	
pr 3.888		883.1	1260.1	837.1	1240.1	1320.1	1270.1	1220.1	1140.1	545.1	1260.1	466.1	1180.1	468.1	0.1	1130.1	18.1	1310.1	9.1	1080.1	1200.1	1050.1	1030.1	
pr 3.142		1590.1	2060.1	1530.1	2240.1	2370.1	2186.1	2270.1	2053.1	768.1	2710.1	791.1	2710.1	747.1	2.1	2700.1	4.1	2940.1	12.1	1940.1	2460.1	1780.1	2470.1	
pr 2.683		34300.1	36400.1	24400.1	31900.1	39800.1	31300.1	37300.1	29800.1	8000.1	46700.1	7760.1	47500.1	7650.1	80.1	45700.1	100.1	46500.1	88.1	28200.1	39900.1	27500.1	40900.1	
pr 2.345		85700.1	124000.1	85400.1	104000.1	127900.1	102000.1	123000.1	88900.1	21600.1	156000.1	20600.1	157000.1	20600.1	227.1	149000.1	307.1	148000.1	208.1	93300.1	131000.1	92200.1	131000.1	
pr 1.990		88900.1	142000.1	97500.1	118000.1	138000.1	113000.1	137000.1	110000.1	19100.1	174300.1	18800.1	172000.1	18300.1	224.1	165000.1	222.1	161000.1	241.1	106000.1	146000.1	103000.1	145000.1	
pr 1.897		104000.1	147000.1	102000.1	119000.1	144000.1	117000.1	142000.1	114000.1	15100.1	179000.1	14800.1	178000.1	14800.1	245.1	170000.1	222.1	169000.1	229.1	111000.1	152000.1	139000.1	151000.1	
pr 1.497		123000.1	171000.1	122000.1	139000.1	166500.1	133000.1	164000.1	131000.1	12900.1	201000.1	12200.1	200000.1	11900.1	264.1	194000.1	280.1	192000.1	233.1	131000.1	175000.1	128000.1	174000.1	
pr 1.296		135000.1	140000.1	103000.1	119000.1	133000.1	109000.1	133000.1	107000.1	6730.1	160000.1	6730.1	160000.1	6620.1	265.1	156000.1	253.1	156000.1	191.1	110000.1	145000.1	126000.1	143000.1	
pr 1.095		74200.1	96200.1	73800.1	75500.1	91100.1	73800.1	91400.1	72600.1	3360.1	108000.1	3210.1	108000.1	3180.1	149.1	106000.1	148.1	105000.1	164.1	78300.1	97900.1	76700.1	97200.1	
pr 0.917		58100.1	75800.1	57500.1	56000.1	70000.1	55500.1	70200.1	54500.1	1750.1	82700.1	1660.1	82500.1	1710.1	120.1	82200.1	104.1	80700.1	105.1	61000.1	75800.1	59700.1	75500.1	
pr 0.798		75400.1	94000.1	74500.1	65400.1	87800.1	64100.1	88200.1	63000.1	1370.1	103000.1	1290.1	101000.1	1330.1	153.1	101000.1	180.1	99800.1	142.1	78300.1	95300.1	76500.1	94300.1	
pr 0.683		33600.1	42700.1	33900.1	24100.1	39500.1	23900.1	40400.1	23600.1	378.1	46600.1	348.1	46500.1	346.1	74.1	45000.1	35.1	45600.1	68.1	35200.1	43300.1	34900.1	42500.1	
pr 0.583		26900.1	35900.1	26700.1	14500.1	31900.1	18000.1	32700.1	13900.1	289.1	38500.1	192.1	38800.1	184.1	42.1	38900.1	22.1	38900.1	47.1	27200.1	32600.1	29900.1	33900.1	
pr 0.498		16700.1	21400.1	16700.1	6852.1	19900.1	4860.1	20500.1	5310.1	247.1	22900.1	45.1	22400.1	85.1	30.1	22600.1	60.1	22700.1	0.1	16400.1	22000.1	14000.1	21200.1	
pr 0.429		7480.1	10900.1	7450.1	1725.1	9600.1	1082.1	10200.1	1330.1	78.1	11100.1	10.1	10700.1	26.1	3.1	11100.1	41.1	10400.1	0.1	7620.1	11300.1	7220.1	10300.1	
pr 0.368		2500.1	3590.1	2450.1	360.1	4080.1	264.1	3210.1	230.1	15.1	3650.1	5.1	3680.1	2.1	0.1	3900.1	23.1	3810.1	0.1	3000.1	3900.1	2870.1	3610.1	
pr 0.314		661.1	1730.1	870.1	82.1	1550.1	49.1	1440.1	100.1	22.1	1570.1	0.1	1870.1	0.1	0.1	1460.1	0.1	1930.1	0.1	1390.1	1370.1	866.1	1470.1	
pr 0.269		0.1	33.1	11.1	7.1	444.1	28.1	261.1	52.1	0.1	555.1	0.1	51.1	0.1	0.1	73.1	0.1	616.1	0.1	0.1	34.1	57.1	14.1	

Collector		Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data
fluid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
deg		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	4	4
stage		S + S1	S + S1	S + S1	S + S1	S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S + S1	S	S	S	S	S	S + S1	S + S1	S + S1	
position		1	2	1	2	2	1	2	1	2	2	1	2	1	2	1	2	2	1	2	1	2	2	1	2
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dp 5.833		571.1	518.1	501.1	516.1	224.1	439.1	229.1	414.1	230.1	1.1	496.1	13.1	508.1	3.1	369.1	370.1	356.1	442.1	351.1	438.1	638.1	368.1		
dp 4.864		2260.1	1870.1	2170.1	1910.1	864.1	2490.1	814.1	2480.1	821.1	10.1	2180.1	22.1	2220.1	14.1	1360.1	2300.1	1500.1	1890.1	1500.1	1960.1	2260.1	1760.1		
dp 4.290		3890.1	3090.1	3900.1	3120.1	1370.1	4340.1	1310.1	4190.1	1320.1	15.1	3560.1	23.1	3680.1	28.1	2430.1	3710.1	2510.1	3390.1	2500.1	3250.1	3660.1	3140.1		
dp 3.668		1020.1	1280.1	1150.1	1270.1	595.1	948.1	574.1	1130.1	497.1	8.1	1080.1	8.1	1140.1	2.1	765.1	818.1	931.1	778.1	962.1	1250.1	1260.1	1240.1		
dp 3.140		3010.1	2750.1	3080.1	2770.1	1080.1	3950.1	1010.1	3350.1	1000.1	13.1	3180.1	7.1	3190.1	8.1	2630.1	3520.1	2660.1	3512.1	2850.1	3810.1	2820.1	2660.1		
dp 2.893		44200.1	36900.1	44000.1	36400.1	15500.1	56400.1	8660.1	55200.1	10000.1	98.1	43700.1	88.1	44000.1	73.1	36300.1	50800.1	35600.1	48300.1	35400.1	36100.1	43300.1	35200.1		
dp 2.345		139000	114000	135000	114000	28900.1	177000	26000.1	174000	29400.1	223.1	136000	224.1	139000	260.1	116000	157000	112000	154000	110000	111000	135000	109000		
dp 1.990		149000	123000	146000	121000	22900.1	188000	22700.1	187000	23200.1	241.1	144000	238.1	143000	212.1	123000	165000	119000	162000	117000	119000	145000	117000		
dp 1.697		155000	129000	154000	126000	18400.1	196000	18300.1	194000	18500.1	233.1	151000	213.1	150000	218.1	133000	170000	129000	173000	127000	125000	153000	122000		
dp 1.497		176000	146000	176000	145000	15500.1	218000	15100.1	216000	15100.1	249.1	173000	261.1	171000	237.1	155000	202000	150000	198000	147000	141000	173000	138000		
dp 1.295		141000	116000	141000	116000	8310.1	172000	8220.1	173000	8340.1	201.1	137000	222.1	138000	186.1	126000	161000	123000	158000	121000	112000	138000	110000		
dp 1.095		86400.1	70500.1	86600.1	70800.1	3650.1	118000	3690.1	118000	3810.1	165.1	93600.1	150.1	93000.1	141.1	83800.1	108000	84300.1	106000	85900.1	75500.1	94200.1	74300.1		
dp 0.927		73600.1	59100.1	73900.1	59800.1	2100.1	88800.1	2120.1	89200.1	2080.1	136.1	72800.1	103.1	72900.1	118.1	69600.1	84600.1	67900.1	83400.1	67300.1	55200.1	72700.1	54300.1		
dp 0.758		91700.1	69600.1	91800.1	69300.1	1560.1	108000	1580.1	107700	1560.1	158.1	89200.1	129.1	89300.1	156.1	86900.1	102000	83600.1	101000	81900.1	60800.1	90000.1	59700.1		
dp 0.583		41300.1	23300.1	41300.1	23200.1	299.1	46300.1	346.1	46200.1	336.1	73.1	40800.1	66.1	39800.1	36.1	37900.1	45100.1	38600.1	21190.1	40200.1	20800.1				
dp 0.583		33000.1	12400.1	32100.1	11900.1	116.1	37800.1	167.1	37700.1	231.1	73.1	32000.1	70.1	31900.1	0.1	29100.1	36900.1	29800.1	34900.1	27700.1	11900.1	31800.1	11800.1		
dp 0.498		20400.1	5060.1	20400.1	4700.1	18.1	23800.1	70.1	22800.1	271.1	74.1	19700.1	21.1	19900.1	35.1	17200.1	22600.1	17000.1	21580.1	15800.1	3840.1	19700.1	6310.1		
dp 0.429		9970.1	1110.1	9892.1	1040.1	7.1	11000.1	14.1	9910.1	98.1	22.1	9530.1	0.1	9510.1	8.1	8100.1	11100.1	7660.1	10300.1	7040.1	819.1	9620.1	1120.1		
dp 0.369		3220.1	189.1	3280.1	234.1	8.1	3640.1	0.1	3580.1	0.1	46.1	3450.1	0.1	3510.1	0.1	2720.1	3550.1	2800.1	3170.1	2120.1	0.1	3270.1	258.1		
dp 0.316		1340.1	58.1	1450.1	48.1	0.1	1360.1	0.1	1312.1	0.1	0.1	1390.1	0.1	1540.1	0.1	974.1	1280.1	834.1	1830.1	656.1	0.1	1150.1	35.1		
dp 0.269		393.1	25.1	74.1	36.1	0.1	2.1	0.1	267.1	0.1	0.1	374.1	0.1	547.1	0.1	0.1	2.1	7.1	79.1	1.1	0.1	11.1	4.1		

Collector		Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data
fluid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
deg		4	4	4	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5	5
stage		S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S	S	S	S	S	S + S1	S + S1	S + S1	S + S1	S + S1	S + S2	S + S2		
position		2	1	2	1	2	2	1	2	1	2	2	1	2	2	1	2	2	1	2	1	2	2	1	2
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dp 5.833		173.1	217.1	173.1	514.1	185.1	4.1	483.1	2.1	444.1	0.1	188.1	353.1	278.1	338.1	304.1	458.1	347.1	403.1	516.1	449.1	184.1	545.1		
dp 4.864		626.1	807.1	643.1	2390.1	833.1	15.1	2210.1	21.1	2200.1	9.1	1130.1	1730.1	1110.1	1630.1	1130.1	1790.1	2210.1	1790.1	2130.1	1590.1	810.1	2310.1		
dp 4.290		1080.1	1520.1	1030.1	3970.1	1110.1	21.1	3660.1	13.1	3660.1	1.1	2030.1	3160.1	1950.1	3130.1	1990.1	3110.1	3550.1	3220.1	3470.1	2690.1	1010.1	3730.1		
dp 3.668		453.1	383.1	393.1	1080.1	442.1	0.1	947.1	0.1	1040.1	0.1	809.1	912.1	851.1	998.1	828.1	1210.1	830.1	1080.1	1010.1	1050.1	414.1	829.1		
dp 3.140		831.1	851.1	919.1	3120.1	815.1	2.1	3180.1	18.1	3080.1	10.1	1830.1	2430.1	1630.1	2290.1	1750.1	2690.1	2780.1	2800.1	2790.1	2710.1	904.1	3350.1		
dp 2.893		8320.1	7870.1	8320.1	46300.1	8170.1	86.1	47500.1	86.1	47200.1	66.1	27200.1	50300.1	26800.1	38500.1	26900.1	37900.1	41700.1	36800.1	43200.1	38900.1	8450.1	48300.1		
dp 2.345		21500.1	39600.1	21200.1	150000	20700.1	235.1	152000	189.1	147000	229.1	90800.1	128000	90100.1	126000	89500.1	117000	138000	115000	138000	115000	21200.1	149000		
dp 1.990		18800.1	17900.1	18900.1	159000	18150.1	232.1	159000	197.1	156000	192.1	101500	141000	100000	141000	99200.1	125000	148000	123000	150000	123000	18400.1	157000		
dp 1.697		19200.1	14600.1	15300.1	169000	14900.1	244.1	168000	215.1	169000	221.1	109000	150000	108000	131000	108000	157000	129000	159000	130000	15000.1	164000			
dp 1.497		12600.1	11800.1	12700.1	186000	12000.1	273.1	191000	237.1	187000	238.1	129000	176000	128000	175000	127000	147000	179000	145000	181000	146000	12900.1	190000		
dp 1.295		8630.1	6850.1	8480.1	151000	8460.1	201.1	152000	187.1	149000	191.1	104000	143000	107000	143000	106000	115000	143000	113000	145000	113000	7080.1	151000		
dp 1.095		3230.1	3180.1	3290.1	104000	3190.1	156.1	103000	158.1	102000	145.1	75600.1	98900.1	76200.1	98400.1	78100.1	94500.1	99700.1	73500.1	99700.1	72600.1	3240.1	104000		
dp 0.927		1750.1	1730.1	1760.1	76700.1	1640.1	125.1	80700.1	103.1	79800.1	97.1	60600.1	78850.1	60600.1	78500.1	60200.1	51800.1	76500.1	51500.1	77000.1	51700.1	1850.1	78700.1		
dp 0.758		1360.1	1290.1	1300.1	81700.1	1320.1	122.1	67400.1	152.1	66300.1	84.1	75600.1	84900.1	76100.1	95500.1	75400.1	52100.1	93800.1	51300.1	94200.1	51300.1	1340.1	96800.1		
dp 0.583		340.1	346.1	353.1	44300.1	316.1	69.1	43900.1	75.1	43200.1	52.1	34600.1	43100.1	34300.1	42900.1	34300.1	38300.1	42100.1	36500.1	42400.1	36200.1	272.1	43200.1		
dp 0.583		158.1	105.1	227.1	34900.1	171.1	62.1	34500.1	28.1	34200.1	50.1	25600.1	34200.1	28600.1	33700.1	29000.1	7620.1	32500.1	7960.1	33600.1	8190.1	124.1	34200.1		
dp 0.498		118.1	29.1	167.1	21900.1	68.1	29.1	21800.1	0.1	21800.1	0.1	15900.1	21500.1	15300.1	20900.1	15700.1	2540.1	20000.1	3260.1	20100.1	2720.1	28.1	21100.1		
dp 0.429		61.1	6.1	120.1	10700.1	8.1	17.1	10000.1	1.1	10400.1	0.1	7010.1	8730.1	6260.1	9630.1	6740.1	648.1	8120.1	1030.1	9680.1	848.1	9.1	10000.1		
dp 0.369		0.1	3.1	0.1	3890.1	2.1	0.1	3360.1	20.1	3380.1	0.1	2240.1	3640.1	2360.1	3210.1	2160.1	180.1	3050.1	249.1	3543.1	165.1	2.1	3340.1		
dp 0.316		0.1	0.1	0.1	1360.1	0.1	0.1	1320.1	0.1	1440.1	0.1	868.1	1500.1	731.1	1340.1	826.1	33.1	1110.1	61.1	1140.1	31.1	0.1	1330.1		
dp 0.269		0.1	0.1	0.1	643.1	0.1	0.1	121	0.1	338.1	0.1	0.1	350.1	126.1	529.1	75.1	8.1	9.1	19.1	19.1	0.1	0.1	0.1		

Collector		Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta
fluid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
day		5	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
stage		S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S	S	S	S	S	S + S1	S + S1	S + S1	S + S1	S + S1	S + S2	S + S2	S + S2	S + S2	S + S2	S + S2	S + S3
position		2	2	1	2	1	2	2	1	2	1	2	2	2	1	2	1	2	2	1	2	1	2	2
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dr 5.833		591.1	0.1	487.1	6.1	432.1	9.1	510.1	372.1	288.1	482.1	328.1	459.1	384.1	434.1	466.1	442.1	204.1	800.1	177.1	536.1	180.1	5.1	
dr 4.954		842.1	0.1	2306.1	17.1	1873.1	19.1	1160.1	1870.1	1160.1	1890.1	1190.1	1750.1	2156.1	1990.1	2100.1	1830.1	623.1	2190.1	628.1	2210.1	574.1	18.1	
dr 4.290		977.1	0.1	3810.1	24.1	3370.1	33.1	2200.1	3350.1	2060.1	3310.1	2040.1	3030.1	3900.1	3040.1	3830.1	3000.1	1040.1	3710.1	1000.1	3720.1	927.1	21.1	
dr 3.886		425.1	0.1	940.1	11.1	1040.1	17.1	920.1	1010.1	772.1	1090.1	849.1	1180.1	1050.1	1080.1	1050.1	1170.1	433.1	1180.1	437.1	1070.1	409.1	13.1	
dr 3.140		845.1	18.1	3210.1	9.1	3060.1	21.1	1960.1	2350.1	1860.1	2470.1	1860.1	2720.1	2960.1	2850.1	2850.1	2880.1	917.1	3010.1	800.1	3040.1	765.1	5.1	
dr 2.863		8160.1	108.1	46100.1	95.1	44500.1	95.1	27900.1	40100.1	27200.1	39500.1	27400.1	36700.1	44200.1	37100.1	44200.1	37000.1	7800.1	45900.1	7600.1	46200.1	7230.1	81.1	
dr 2.345		21000.1	239.1	144000	219.1	140000	266.1	91700.1	133000	90700.1	132000	91100.1	118000	141000	117000	141000	115000	20200.1	145000	19800.1	145000	19800.1	226.1	
dr 1.990		17900.1	212.1	151000	234.1	148000	246.1	103000	145000	101000	146000	102000	129000	152000	124000	150000	122000	17800.1	154000	17400.1	154000	17400.1	187.1	
dr 1.657		14700.1	245.1	161000	262.1	158000	273.1	109000	156000	109000	154000	110000	132000	162000	131000	160000	128000	14800.1	162000	14000.1	163000	14000.1	177.1	
dr 1.407		12400.1	294.1	183000	298.1	180000	276.1	128000	179000	129000	180000	129000	145000	185000	140000	183000	140000	13200.1	183000	11800.1	185000	12000.1	196.1	
dr 1.206		8710.1	314.1	145000	201.1	144000	228.1	108000	146000	108000	147000	108000	107000	147000	105000	147000	103000	8790.1	148000	8570.1	148000	8670.1	153.1	
dr 1.055		3220.1	187.1	99800.1	140.1	98400.1	158.1	77400.1	100000	74800.1	101000	75800.1	82900.1	102000	82000.1	101000	80700.1	3140.1	101000	3180.1	101000	3200.1	114.1	
dr 1.055		3220.1	187.1	99800.1	140.1	98400.1	158.1	77400.1	100000	74800.1	101000	75800.1	82900.1	102000	82000.1	101000	80700.1	3140.1	101000	3180.1	101000	3200.1	114.1	
dr 0.927		1720.1	120.1	77000.1	122.1	76300.1	122.1	60900.1	77800.1	60700.1	78300.1	60700.1	59900.1	78900.1	59300.1	78400.1	58100.1	1790.1	78400.1	1770.1	78700.1	1790.1	104.1	
dr 0.799		1350.1	156.1	94100.1	120.1	93000.1	146.1	77100.1	97200.1	76900.1	97800.1	76900.1	74500.1	98000.1	74600.1	96200.1	73800.1	1350.1	96400.1	1390.1	96300.1	1343.1	107.1	
dr 0.683		341.1	46.1	42300.1	90.1	41800.1	86.1	34900.1	44200.1	35100.1	44400.1	34600.1	9470.1	43700.1	10100.1	43300.1	9770.1	381.1	43400.1	347.1	43500.1	294.1	48.1	
dr 0.583		501.1	31.1	33700.1	14.1	32700.1	74.1	29600.1	35100.1	29400.1	35300.1	29500.1	5370.1	34600.1	4950.1	34500.1	5380.1	127.1	33800.1	347.1	34200.1	95.1	16.1	
dr 0.498		312.1	8.1	20500.1	44.1	20400.1	78.1	16100.1	22000.1	15700.1	22100.1	15800.1	2210.1	21800.1	2230.1	21400.1	2230.1	88.1	21200.1	344.1	21700.1	22.1	6.1	
dr 0.429		80.1	3.1	9290.1	31.1	9630.1	24.1	7390.1	10900.1	6950.1	10700.1	7040.1	778.1	10500.1	815.1	9950.1	810.1	14.1	10500.1	98.1	10600.1	8.1	8.1	
dr 0.389		0.1	5.1	3520.1	4.1	3540.1	0.1	2340.1	3840.1	2260.1	3670.1	2430.1	215.1	3600.1	197.1	3500.1	256.1	0.1	3320.1	37.1	3510.1	0.1	0.1	
dr 0.314		0.1	0.1	1300.1	0.1	1380.1	0.1	997.1	1670.1	838.1	1610.1	824.1	53.1	1500.1	48.1	1310.1	73.1	0.1	1390.1	0.1	1520.1	0.1	0.1	
dr 0.269		0.1	0.1	341.1	0.1	364.1	0.1	0.1	310.1	7.1	0.1	0.1	0.1	502.1	0.1	320.1	11.1	0.1	234.1	0.1	231.1	0.1	0.1	

Collector		Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta	Mon_Seta
fluid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
day		6	6	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
stage		S + S3	S + S3	S	S	S	S	S	S + S1	S + S1	S + S1	S + S1	S + S1	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S + S3	S + S3	S + S3
position		1	2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	2
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dr 5.833		383.1	3.1	259.1	306.1	347.1	366.1	228.1	438.1	350.1	462.1	351.1	357.1	235.1	275.1	186.1	187.1	206.1	3.1	385.1	8.1	438.1	3.1	
dr 4.954		2120.1	17.1	915.1	1180.1	943.1	1540.1	1020.1	1630.1	1910.1	1880.1	1770.1	1510.1	743.1	2180.1	704.1	1940.1	870.1	15.1	1800.1	3.1	1880.1	13.1	
dr 4.290		3630.1	15.1	1850.1	2840.1	1870.1	2930.1	1870.1	3030.1	3410.1	3170.1	3290.1	2830.1	1340.1	3810.1	1230.1	3690.1	1180.1	28.1	3690.1	0.1	3680.1	22.1	
dr 3.886		1120.1	15.1	838.1	1120.1	878.1	1090.1	838.1	1330.1	1300.1	1310.1	1130.1	1080.1	887.1	1060.1	564.1	1140.1	574.1	3.1	1290.1	11.1	1310.1	20.1	
dr 3.140		2980.1	12.1	1230.1	1880.1	1440.1	1740.1	1400.1	1990.1	1970.1	2000.1	2010.1	1900.1	872.1	2290.1	882.1	2120.1	771.1	17.1	1960.1	28.1	2120.1	16.1	
dr 2.863		44900.1	83.1	21500.1	31500.1	22000.1	32100.1	21900.1	32100.1	37500.1	32300.1	37300.1	36700.1	9250.1	46000.1	9940.1	45800.1	8800.1	87.1	39600.1	86.1	39400.1	90.1	
dr 2.345		147000	201.1	79300.1	113000	79400.1	114000	78200.1	110000	132000	109000	131000	107000	29600.1	164000	25500.1	161000	24600.1	217.1	137000	216.1	134000	217.1	
dr 1.990		158000	184.1	84300.1	121000	92500.1	131000	90300.1	123000	147000	122000	147000	126000	24200.1	184000	23400.1	181000	23100.1	218.1	153000	203.1	152000	240.1	
dr 1.657		146000	188.1	97900.1	135000	96400.1	138000	95100.1	124000	153000	122000	153000	121000	19400.1	189000	18900.1	187000	18600.1	235.1	156000	219.1	156000	220.1	
dr 1.407		160000	249.1	119000	163000	118000	161000	115000	139000	176000	135000	176000	133000	18800.1	217000	18100.1	216000	15900.1	248.1	183000	280.1	180000	256.1	
dr 1.206		153000	180.1	102000	135000	100000	134000	95700.1	98100.1	146000	96600.1	146000	97000.1	9340.1	174000	8960.1	175000	9200.1	242.1	148000	196.1	145000	240.1	
dr 1.055		124000	142.1	73100.1	93900.1	71400.1	93000.1	70200.1	55900.1	101000	55500.1	100000	54600.1	4530.1	119000	4470.1	119000	4450.1	152.1	102000	145.1	101000	127.1	
dr 1.055		124000	142.1	73100.1	93900.1	71400.1	93000.1	70200.1	55900.1	101000	55500.1	100000	54600.1	4530.1	119000	4470.1	119000	4450.1	152.1	102000	145.1	101000	127.1	
dr 0.927		81100.1	89.1	57300.1	72900.1	55800.1	71400.1	55100.1	34200.1	77500.1	33900.1	76900.1	33600.1	2430.1	90200.1	2350.1	90400.1	2360.1	114.1	78300.1	113.1	78600.1	126.1	
dr 0.799		99500.1	136.1	74800.1	97100.1	73100.1	92300.1	71300.1	31400.1	97400.1	30800.1	96900.1	31000.1	1870.1	114000	1840.1	113000	1910.1	127.1	88200.1	133.1	87400.1	132.1	
dr 0.683		44100.1	56.1	33700.1	42100.1	32500.1	41700.1	32200.1	9320.1	44900.1	9270.1	43900.1	9270.1	507.1	50000.1	384.1	50300.1	398.1	63.1	44400.1	59.1	43600.1	82.1	
dr 0.583		38100.1	48.1	28300.1	33500.1	28800.1	33300.1	24800.1	5240.1	35400.1	5210.1	34600.1	5310.1	324.1	40400.1	111.1	40400.1	118.1	40.1	35200.1	0.1	34800.1	38.1	
dr 0.498		22300.1	43.1	15900.1	21300.1	15800.1	21100.1	15100.1	3090.1	22700.1	3060.1	22300.1	3200.1	296.1	25800.1	28.1	25300.1	35.1	0.1	22700.1	36.1	21800.1	8.1	
dr 0.429		10900.1	19.1	7450.1	10700.1	7030.1	10500.1	5800.1	1540.1	11000.1	498.1	10500.1	1380.1	118.1	13500.1	9.1	12900.1	10.1	0.1	11100.1	0.1	11000.1	1.1	
dr 0.389		3750.1	0.1	2610.1	3590.1	2250.1	3570.1	2150.1	895.1	4130.1	97.1	4110.1	503.1	0.1	4790.1	2.1	4590.1	2.1	0.1	4340.1	0.1	3890.1	12.1	
dr 0.314		1580.1	30.1	628.1	1960.1	823.1	1850.1	735.1	142.1	1420.1	20.1	1410.1	93.1	0.1	1150.1	0.1	1480.1	0.1	14.1	809.1	0.1	1320.1	0.1	
dr 0.269		151.1	0.1	139.1	219.1	12.1	426.1	0.1	0.1	16.1	0.1	66.1	0.1	0.1	203.1	0.1	436.1	0.1	0.1	0.1	0.1	117.1	0.1	

Collector		Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data
fluid		C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1
day		8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	9	9	9	9
stage		S	S	S	S + S1	S + S1	S + S1	S + S1	S + S1	S + S2	S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S	S	S	S	S	S
position		2	1	2	2	1	2	1	2	2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	1
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dr= 5.833		276.1	443.1	275.1	551.1	239.1	508.1	375.1	535.1	243.1	380.1	195.1	341.1	308.1	6.1	526.1	4.1	458.1	8.1	282.1	269.1	186.1	332.1	276.1
dr= 4.964		1220.1	1950.1	1140.1	2280.1	2273.1	3180.1	2240.1	2240.1	773.1	2190.1	977.1	2120.1	894.1	18.1	2050.1	9.1	2010.1	23.1	975.1	1640.1	1080.1	1730.1	1220.1
dr= 4.290		2050.1	3200.1	1960.1	4070.1	4000.1	3750.1	3970.1	3780.1	1210.1	3490.1	1670.1	3590.1	1180.1	24.1	3560.1	17.1	3640.1	18.1	1980.1	3030.1	2020.1	3100.1	2050.1
dr= 3.668		838.1	1060.1	807.1	1380.1	753.1	1290.1	778.1	1380.1	503.1	725.1	482.1	848.1	473.1	7.1	862.1	8.1	1010.1	12.1	881.1	943.1	764.1	1070.1	838.1
dr= 3.140		1950.1	2460.1	1880.1	3220.1	2660.1	3220.1	2810.1	3250.1	892.1	2680.1	894.1	3010.1	832.1	10.1	2890.1	14.1	2780.1	9.1	1500.1	1830.1	1600.1	1900.1	1950.1
dr= 2.693		27450.1	36000.1	26500.1	46200.1	53100.1	47100.1	52900.1	46500.1	9330.1	50000.1	9040.1	49600.1	8770.1	58.1	43600.1	85.1	44600.1	73.1	24800.1	35300.1	25200.1	36700.1	27450.1
dr= 2.345		89500.1	126000	88100.1	156000	174000	150000	172000	148000	24430.1	165000	23900.1	161000	23700.1	205.1	143000	177.1	144000	202.1	84600.1	126000	87400.1	128000	89500.1
dr= 1.990		96000.1	137000	94900.1	166000	188000	160000	186000	159000	21600.1	178000	21100.1	174000	21000.1	166.1	155000	172.1	155000	152.1	93000	143000	100000	144000	96000.1
dr= 1.697		106000	148000	103000	170000	198000	165000	196000	164000	17500.1	189000	17200.1	183000	17500.1	173.1	164000	163.1	163000	158.1	139000	151000	107000	152000	106000
dr= 1.497		125000	171000	122000	182000	225000	178000	222000	175000	15100.1	211000	14700.1	211000	14500.1	200.1	187000	190.1	187000	190.1	133000	179000	127000	179000	125000
dr= 1.296		105000	138000	102000	126000	179000	123000	177000	123000	8420.1	166000	8030.1	167000	8245.1	143.1	151000	142.1	150000	149.1	111000	147000	109000	149000	105000
dr= 1.095		74400.1	99200.1	72600.1	70600.1	122000	89200.1	121000	88200.1	4100.1	115000	3960.1	113000	3960.1	108.1	104000	115.1	102000	98.1	78100.1	101000	77700.1	101000	74400.1
dr= 0.927		58000.1	74500.1	57500.1	42500.1	93900.1	41300.1	94100.1	41800.1	2270.1	88600.1	2080.1	88100.1	2140.1	75.1	80300.1	74.1	79800.1	66.1	61800.1	78200.1	61300.1	78200.1	58000.1
dr= 0.798		74700.1	93000.1	72300.1	37300.1	114000	36200.1	114000	36500.1	1630.1	109000	1710.1	107000	1730.1	120.1	99600.1	94.1	97200.1	103.1	80100.1	100000	78500.1	99700.1	74700.1
dr= 0.693		33500.1	41800.1	33000.1	10600.1	51100.1	11100.1	50900.1	10900.1	430.1	44900.1	368.1	48700.1	448.1	77.1	44600.1	57.1	44200.1	48.1	36000.1	45200.1	35300.1	44800.1	33500.1
dr= 0.583		25700.1	33000.1	25100.1	6100.1	39400.1	5990.1	39500.1	5800.1	182.1	36000.1	204.1	38000.1	217.1	51.1	34800.1	47.1	34800.1	32.1	28000.1	36200.1	27400.1	36100.1	25700.1
dr= 0.488		15300.1	20600.1	15100.1	2020.1	23900.1	2820.1	24800.1	2400.1	18.1	23600.1	126.1	23500.1	167.1	14.1	22500.1	18.1	21800.1	10.1	16800.1	23500.1	16800.1	23000.1	15300.1
dr= 0.429		8970.1	9940.1	8950.1	504.1	10600.1	1120.1	11900.1	534.1	15.1	12000.1	38.1	11800.1	72.1	5.1	10900.1	0.1	10400.1	6.1	7760.1	11600.1	7530.1	11400.1	8970.1
dr= 0.369		2170.1	3360.1	2170.1	104.1	4390.1	317.1	4350.1	113.1	0.1	4250.1	9.1	3900.1	17.1	0.1	3790.1	0.1	3310.1	14.1	3400.1	4180.1	2210.1	4180.1	2170.1
dr= 0.314		722.1	1010.1	850.1	25.1	1600.1	76.1	1660.1	17.1	0.1	1460.1	2.1	1690.1	0.1	0.1	1840.1	0.1	1700.1	0.1	782.1	1640.1	1140.1	1770.1	722.1
dr= 0.269		4.1	9.1	179.1	4.1	445.1	14.1	381.1	4.1	0.1	583.1	0.1	382.1	0.1	11.1	737.1	0.1	512.1	0.1	140.1	188.1	87.1	311.1	4.1

Collector		Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data	Mon_Data
fluid		C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1	C14/15/1
day		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	11	11	11	11	11	12	12	12
stage		S + S1	S + S1	S + S1	S + S1	S + S2	S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3	S	S	S	S	S	S	S + S1	S + S1	S + S1	
position		1	2	1	2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	2	1	2	2	1	2
		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dr= 5.833		417.1	458.1	375.1	473.1	192.1	444.1	149.1	441.1	159.1	8.1	466.1	5.1	308.1	0.1	197.1	154.1	188.1	247.1	160.1	368.1	443.1	438.1	417.1
dr= 4.964		1830.1	1990.1	1900.1	1660.1	561.1	1970.1	532.1	1950.1	533.1	15.1	2020.1	17.1	1970.1	11.1	1180.1	1680.1	1200.1	1530.1	1110.1	1470.1	1970.1	1560.1	1830.1
dr= 4.290		3340.1	2820.1	3390.1	2810.1	893.1	3360.1	858.1	3060.1	867.1	19.1	3430.1	23.1	3390.1	22.1	2430.1	3660.1	2630.1	3490.1	2360.1	3060.1	3660.1	2660.1	3340.1
dr= 3.668		1220.1	1110.1	1210.1	1100.1	368.1	923.1	370.1	928.1	347.1	11.1	1040.1	3.1	948.1	11.1	1220.1	1250.1	1110.1	1270.1	1170.1	1360.1	1210.1	1280.1	1220.1
dr= 3.140		2410.1	2510.1	2480.1	2370.1	723.1	2700.1	716.1	2580.1	688.1	26.1	2900.1	4.1	2740.1	5.1	1170.1	1210.1	1070.1	1300.1	1130.1	1800.1	1740.1	1920.1	2410.1
dr= 2.693		40700.1	33800.1	40100.1	30600.1	7400.1	42100.1	7020.1	41400.1	6910.1	72.1	41800.1	61.1	42700.1	74.1	28000.1	38500.1	27100.1	37500.1	26700.1	31000.1	37100.1	30000.1	40700.1
dr= 2.345		136000	119000	134000	109000	19500.1	138000	19100.1	135000	18600.1	185.1	138000	164.1	137000	211.1	106000	149000	103000	143000	102000	107000	130000	103000	136000
dr= 1.990		149000	126000	147000	115000	17400.1	147000	17100.1	146000	16600.1	194.1	148000	163.1	147000	160.1	113000	174000	125000	172000	123000	121000	148000	117000	149000
dr= 1.697		157000	129000	154000	123000	14200.1	157000	13800.1	155000	13600.1	165.1	157000	164.1	155000	178.1	137000	181000	133000	177000	124000	124000	158000	121000	157000
dr= 1.497		181000	138000	178000	137000	12200.1	181000	12000.1	178000	11500.1	208.1	181000	188.1	179000	198.1	163000	212000	157000	209000	155000	143000	179000	137000	181000
dr= 1.296		146000	103000	144000	102000	8790.1	145000	8690.1	143000	8560.1	172.1	145000	163.1	143000	164.1	139000	178000	135000	174000	131000	110000	146000	107000	146000
dr= 1.095		100000	69400.1	98200.1	68600.1	3300.1	99700.1	3210.1	98600.1	3160.1	133.1	99300.1	121.1	98100.1	122.1	99000.1	121000	93200.1	119000	93400.1	88500.1	99800.1	88000.1	100000
dr= 0.927		78000.1	58100.1	76700.1	58000.1	1710.1	77300.1	1720.1	76900.1	1720.1	78.1	77800.1	97.1	76800.1	62.1	79200.1	91400.1	73100.1	90700.1	71700.1	43100.1	76300.1	41700.1	78000.1
dr= 0.798		96800.1	80400.1	95600.1	80700.1	1340.1	95000.1	1370.1	94300.1	1220.1	119.1	95400.1	121.1	94300.1	117.1	96500.1	116000	96100.1	116000	94200.1	58200.1	96200.1	57000.1	96800.1
dr= 0.693		44100.1	8700.1	43300.1	8420.1	340.1	43000.1	298.1	42600.1	370.1	51.1	43900.1	46.1	42900.1	36.1	43400.1	52400.1	42400.1	51400.1	41500.1	9970.1	43800.1	9980.1	44100.1
dr= 0.583		35200.1	9980.1	34300.1	8470.1	104.1	34100.1	218.1	33800.1	138.1	33.1	34400.1	10.1	33800.1	33.1	34300.1	42400.1	33300.1	41500.1	33000.1	5050.1	34900.1	4750.1	35200.1
dr= 0.488		22000.1	1570.1	21900.1	1910.1	26.1	21900.1	151.1	21500.1	52.1	0.1	21900.1	0.1	21700.1	0.1	22000.1	26500.1	19600.1	26200.1	19700.1	1770.1	20300.1	1690.1	22000.1
dr= 0.429		10700.1	323.1	10600.1	744.1	8.1	10400.1	83.1	10400.1	8.1	0.1	10600.1	0.1	10400.1	0.1	9050.1	13500.1	8900.1	12800.1	9020.1	298.1	9450.1	430.1	10700.1
dr= 0.369		3650.1	69.1	3772.1	188.1	5.1	3550.1	21.1	3690.1	0.1	0.1	3560.1	0.1	3710.1	0.1	2650.1	4515.1	2780.1	4160.1	2910.1	74.1	3920.1	81.1	3650.1
dr= 0.314		1380.1	12.1	1570.1	33.1	0.1	1400.1	0.1	1410.1	0.1	0.1	1390.1	0.1	1530.1	0.1	1040.1	2520.1	1040.1	2030.1	1060.1	18.1	1930.1	19.1	1380.1
dr= 0.269		30.1	0.1	5.1	2.1	0.1	67.1	0.1	367.1	0.1	0.1	297.1	16.1	423.1	0.1	68.1	814.1	319.1	208.1	230.1	2.1	390.1	4.1	30.1

Colector		Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta	Mon_3eta
fuid		C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1	C14/16/1
dig		13	13	13	13	13	14	14	14	14	14
stage		S + S2	S + S2	S + S2	S + S2	S + S2	S + S3	S + S3	S + S3	S + S3	S + S3
position		2	1	2	1	2	3	1	2	1	2
		0	0	0	0	0	0	0	0	0	0
d= 5.833		234.1	238.1	187.1	345.1	199.1	0.1	453.1	3.1	441.1	3.1
d= 4.964		731.1	2130.1	697.1	2140.1	732.1	18.1	1890.1	12.1	1880.1	16.1
d= 4.200		1360.1	4170.1	1230.1	4140.1	1220.1	20.1	3780.1	16.1	3620.1	25.1
d= 3.568		615.1	1170.1	499.1	1280.1	612.1	11.1	1280.1	11.1	1280.1	17.1
d= 3.140		717.1	2270.1	738.1	2160.1	773.1	15.1	1940.1	7.1	1660.1	10.1
d= 2.693		8210.1	46000.1	8110.1	47900.1	8490.1	66.1	37100.1	69.1	38000.1	104.1
d= 2.345		23000.1	164000	22600.1	164000	23100.1	224.1	126000	192.1	125000	194.1
d= 1.990		21200.1	184000	20800.1	183000	21100.1	212.1	144000	216.1	143000	211.1
d= 1.697		18800.1	190000	16100.1	190000	16800.1	189.1	148000	198.1	148000	181.1
d= 1.497		14200.1	215000	13900.1	216000	14200.1	235.1	170000	187.1	169000	238.1
d= 1.296		8520.1	174000	8110.1	173000	8390.1	191.1	139000	182.1	137000	164.1
d= 1.095		4510.1	118000	4250.1	117000	4360.1	118.1	95500.1	138.1	94300.1	132.1
d= 0.927		2840.1	88700.1	2720.1	88300.1	2660.1	84.1	72100.1	112.1	71200.1	93.1
d= 0.786		2970.1	112000	2890.1	111000	3010.1	125.1	92100.1	131.1	91000.1	126.1
d= 0.663		1120.1	49300.1	1040.1	49300.1	1110.1	52.1	40800.1	15.1	40000.1	53.1
d= 0.563		730.1	39100.1	711.1	38600.1	776.1	37.1	32400.1	36.1	31500.1	45.1
d= 0.498		428.1	24500.1	413.1	24500.1	536.1	26.1	20200.1	0.1	19700.1	46.1
d= 0.429		160.1	12700.1	281.1	12100.1	317.1	21.1	9830.1	0.1	9720.1	30.1
d= 0.369		41.1	4700.1	111.1	3610.1	168.1	0.1	3690.1	0.1	3530.1	0.1
d= 0.314		3.1	1520.1	30.1	1420.1	34.1	0.1	1150.1	0.1	1270.1	0.1
d= 0.269		0.1	157.1	0.1	752.1	0.1	11.1	183.1	4.1	178.1	0.1

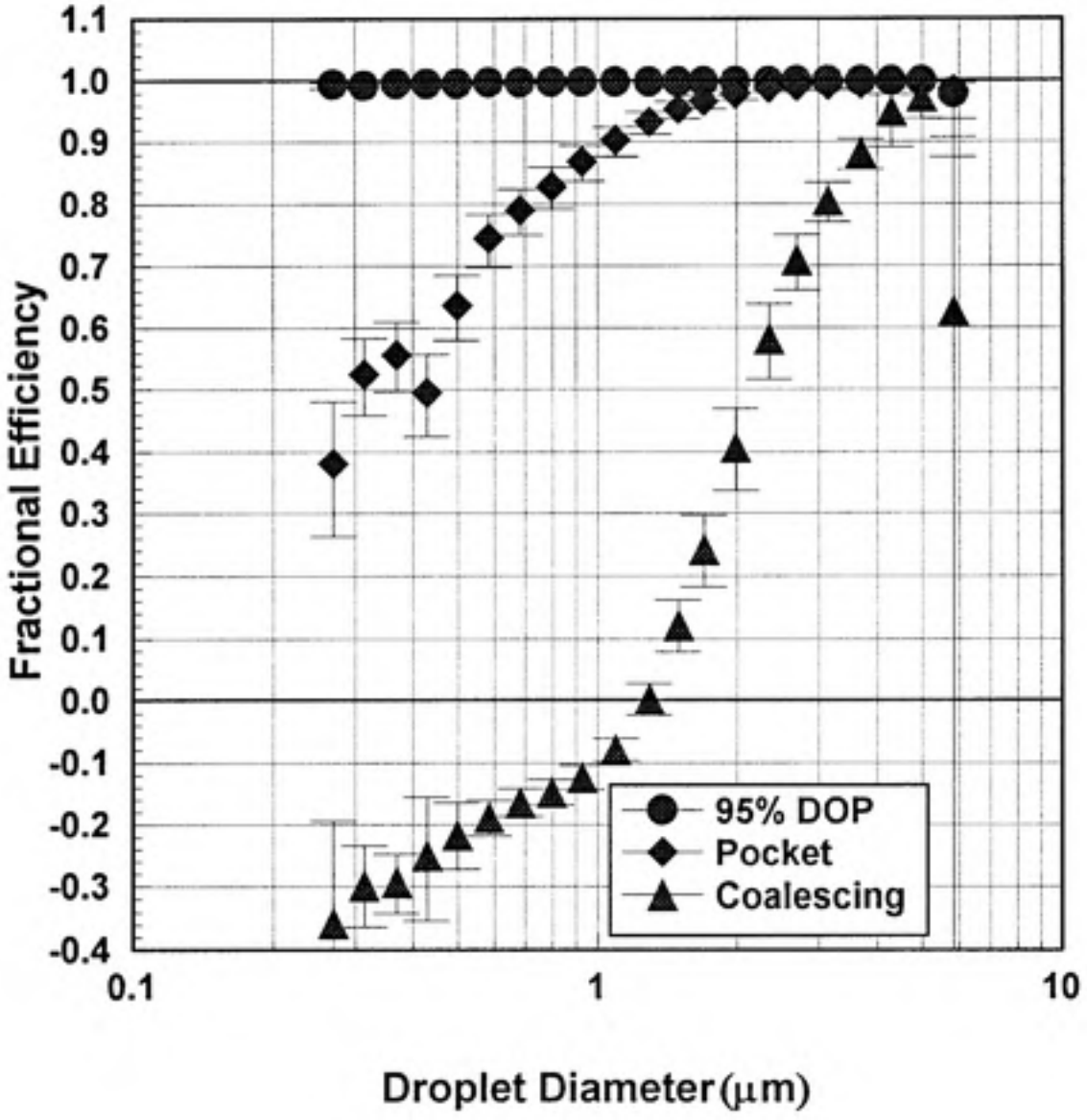

FIGURE B1: Fractional efficiency of coalescing, pocket, and 95% DOP filters for alkane oil. Error bars represent 95% confidence intervals.

Table B2	Count data for efficiency tests using oleic acid as a test fluid									
Collect	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag
Fluid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid	Ol_Acid
Test	1	1	1	1	1	2	2	2	2	2
Conc	low	low	low	low	low	low	low	low	low	low
Stages	S	S	S	S	S	S	S	S	S	S
Flow	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Position	2	1	2	1	2	2	1	2	1	2
diameter, um										
5.833	95.1	89.1	95.1	75.1	107.1	82.1	80.1	91.1	64.1	91.1
4.984	439.1	447.1	399.1	389.1	384.1	360.1	395.1	384.1	361.1	389.1
4.29	814.1	765.1	713.1	758.1	673.1	721.1	763.1	700.1	652.1	662.1
3.688	385.1	397.1	320.1	384.1	382.1	313.1	383.1	323.1	340.1	315.1
3.14	884.1	964.1	926.1	886.1	915.1	891.1	844.1	870.1	865.1	884.1
2.693	9040.1	9140.1	8820.1	8960.1	8840.1	8510.1	8560.1	8310.1	7980.1	8210.1
2.345	25300.1	25200.1	24800.1	25100.1	24400.1	23500.1	23900.1	23100.1	23000.1	22800.1
1.99	25000.1	25000.1	24300.1	25000.1	24400.1	23400.1	23700.1	22600.1	22500.1	22700.1
1.697	23300.1	23800.1	23400.1	23600.1	23000.1	22400.1	22600.1	21500.1	21700.1	21500.1
1.497	24700.1	25300.1	24400.1	25300.1	24400.1	23800.1	24200.1	22600.1	23000.1	22700.1
1.296	18100.1	18700.1	17700.1	18600.1	17900.1	17500.1	17900.1	16600.1	17100.1	16700.1
1.095	12100.1	12700.1	12100.1	13000.1	12200.1	11900.1	12300.1	11500.1	11700.1	11400.1
0.927	8900.1	9560.1	8580.1	9320.1	8880.1	8550.1	9110.1	8090.1	8470.1	8170.1
0.798	10900.1	12000.1	10600.1	11600.1	10800.1	10500.1	11300.1	10200.1	11100.1	10200.1
0.683	4780.1	5630.1	4580.1	5460.1	4710.1	4470.1	5340.1	4360.1	5060.1	4490.1
0.583	3900.1	5000.1	3930.1	4960.1	4040.1	3820.1	4680.1	3820.1	4630.1	3820.1
0.498	2650.1	3490.1	2380.1	3640.1	2610.1	2550.1	3420.1	2380.1	3170.1	2360.1
0.429	1360.1	1960.1	1270.1	2220.1	1430.1	1360.1	2100.1	1120.1	1990.1	1300.1
0.369	646.1	901.1	458.1	1070.1	639.1	596.1	970.1	435.1	913.1	691.1
0.314	288.1	456.1	207.1	663.1	266.1	271.1	499.1	165.1	513.1	383.1
0.269	73.1	150.1	45.1	198.1	59.1	52.1	139.1	48.1	173.1	134.1

Table B3	Count data for efficiency tests using mineral oil as a test fluid																				
Collect	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag	Mon_3stag
Fluid	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil	Min_Oil
Day	1	1	1	1	1	4	4	4	4	4	4	9	9	9	9	9	14	14	14	14	14
Conc	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high	high
Stages	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Flow	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Position	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	2	1	2	1	2	
diameter, um																					
5.833	206.1	280.1	278.1	351.1	262.1	346.1	280.1	324.1	305.1	324.1	229.1	377.1	274.1	418.1	259.1	244.1	257.1	330.1	275.1	250.1	
4.994	1020.1	1740.1	1080.1	1760.1	1020.1	1720.1	2050.1	1200.1	2190.1	1230.1	1200.1	1900.1	1210.1	2020.1	1080.1	1180.1	1880.1	1130.1	1790.1	1040.1	
4.29	1590.1	3200.1	1810.1	3120.1	1830.1	2000.1	3460.1	2010.1	3690.1	1980.1	1790.1	3080.1	1740.1	3280.1	1700.1	1890.1	3390.1	1810.1	3110.1	1820.1	
3.888	587.1	1070.1	674.1	982.1	693.1	709.1	827.1	684.1	1020.1	643.1	629.1	623.1	571.1	820.1	605.1	699.1	1080.1	649.1	858.1	572.1	
3.14	2490.1	3580.1	2640.1	3570.1	2620.1	2850.1	4500.1	3020.1	4230.1	3100.1	2950.1	4060.1	3070.1	4420.1	2880.1	2540.1	3600.1	2570.1	3610.1	2480.1	
2.693	27800.1	46900.1	28400.1	47000.1	28900.1	32300.1	53400.1	31400.1	53000.1	33700.1	31300.1	49800.1	30800.1	48600.1	30200.1	29500.1	47100.1	28200.1	46100.1	28900.1	
2.345	66300.1	142000.1	67200.1	142000.1	67700.1	88000.1	160000.1	93500.1	159000.1	102000.1	94100.1	149000.1	91600.1	143000.1	88400.1	90500.1	144000.1	90400.1	141000.1	86700.1	
1.99	83300.1	150000.1	84100.1	149000.1	84700.1	104000.1	163000.1	98900.1	162000.1	107000.1	98200.1	150000.1	96300.1	144000.1	92500.1	97900.1	150000.1	97400.1	148000.1	97300.1	
1.697	103000.1	157000.1	104000.1	155000.1	105000.1	114000.1	168000.1	106000.1	167000.1	118000.1	109000.1	156000.1	109000.1	151000.1	102000.1	107000.1	156000.1	107000.1	156000.1	107000.1	
1.497	124000.1	179000.1	125000.1	178000.1	126000.1	134000.1	186000.1	127000.1	186000.1	139000.1	129000.1	180000.1	126000.1	173000.1	123000.1	127000.1	177000.1	126000.1	176000.1	127000.1	
1.298	109000.1	145000.1	108000.1	146000.1	106000.1	111000.1	148000.1	107000.1	149000.1	114000.1	107000.1	146000.1	105000.1	139000.1	102000.1	108000.1	141000.1	104000.1	140000.1	105000.1	
1.095	77700.1	103000.1	78900.1	104000.1	78500.1	81800.1	107000.1	78800.1	106000.1	84800.1	80300.1	104000.1	78500.1	101000.1	76800.1	77300.1	101000.1	77900.1	101000.1	77900.1	
0.927	64500.1	83900.1	65000.1	83800.1	65300.1	68100.1	85000.1	63200.1	85400.1	68300.1	64100.1	82800.1	62700.1	79800.1	60900.1	63800.1	81300.1	63500.1	82000.1	63800.1	
0.798	83300.1	105000.1	83500.1	105000.1	83900.1	84000.1	108000.1	81000.1	107000.1	87700.1	82500.1	106000.1	80800.1	102000.1	78800.1	81300.1	102000.1	81100.1	102000.1	80700.1	
0.683	40100.1	51000.1	40800.1	51400.1	40500.1	40100.1	51700.1	39800.1	51900.1	42000.1	39800.1	50800.1	39200.1	48900.1	37500.1	39000.1	49900.1	39200.1	50700.1	39400.1	
0.583	35500.1	45200.1	35600.1	44800.1	35800.1	35400.1	45900.1	34300.1	46500.1	36800.1	35100.1	46100.1	34400.1	45100.1	33300.1	34600.1	44200.1	34500.1	45000.1	34200.1	
0.489	24500.1	32800.1	24600.1	32700.1	24800.1	24600.1	33800.1	23800.1	33900.1	25700.1	24500.1	33700.1	23700.1	32700.1	23100.1	24000.1	32500.1	24100.1	33100.1	24400.1	
0.429	14400.1	20600.1	14500.1	20700.1	14300.1	14400.1	21800.1	14000.1	21800.1	15100.1	14300.1	22300.1	14200.1	21500.1	13800.1	14800.1	21300.1	14600.1	21800.1	14600.1	
0.369	6450.1	10300.1	6510.1	10100.1	6290.1	6180.1	11000.1	6070.1	11200.1	6750.1	6210.1	11200.1	6240.1	10800.1	6090.1	6760.1	11000.1	6530.1	10900.1	6770.1	
0.314	3470.1	6750.1	3780.1	6940.1	3670.1	3320.1	6870.1	3600.1	7350.1	3700.1	3530.1	7620.1	3450.1	7030.1	3240.1	3780.1	7230.1	3480.1	6500.1	3670.1	
0.269	1520.1	2980.1	1330.1	3230.1	1460.1	1520.1	2980.1	1540.1	3920.1	1640.1	1320.1	3360.1	1530.1	2950.1	1110.1	1620.1	3470.1	1490.1	2990.1	1210.1	

Table 84 Mass Balance Experiment Vapor Measurement Data

Sample		Concentration mg/m^3 day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9	day 10	day 11
1st Housing	c14		0.88	0.88	0.43	0.44	0.89	0.88	0.86	0.9		0.72
	c16		1.1	1.34	1.26	1.13	1.29	1.19	1.17	1.24		1.58
	c18		0.14	0.25	0.23	0.26	0.33	0.24	0.18	0.19		0.47
	c20		0.003	0.011	0.015	0.009	0.011	0.013	0.013	0.009		0.014
	total		2.1	2.46	1.92	1.84	2.52	2.3	2.23	2.34		2.78
Coalescing	c14		1.46		0.65	1.2	1.6	1.9	1.72	1.79		
	c16		2.17		2.04	2.38	2.4	2.64	2.2	2.5		
	c18		0.22	Low	0.27	0.3	0.53	0.38	0.31	0.3		
	c20		0.003		0.01	0.005	0.017	0.009	0.011	0.008		
	total		3.85		2.97	3.89	4.64	4.91	4.24	4.6		
2nd Housing	c14		0.74	1.04	0.58	0.5	0.62	0.46	0.55	0.6		
	c16		1.05	1.3	1.1	1.23	1.18	0.77	1.13	1.05		
	c18		0.21	0.26	0.19	0.35	0.33	0.25	0.24	0.2		
	c20		0.005	0.007	0.006	0.01	0.006	0.01	0.008	0.006		
	total		2	2.61	1.88	2.09	2.14	1.49	1.93	1.85		
Pocket	c14		2.24	1.56	0.52	1.26	2.6	2.11	2.5	2.23		
	c16		2.91	2.85	3.47	3.07	2.99	2.14	2.56	3.03		
	c18		0.29	0.32	0.33	0.36	0.4	0.3	0.35	0.35		
	c20		0.004	0.008	0.01	0.008	0.017	0.007	0.009	0.005		
	total		5.44	4.74	4.33	4.65	6.01	4.55	5.42	5.62		
3rd Housing	c14		0.42	0.49	0.43	0.44	0.39	0.5	0.47	0.47		
	c16		1.05	1.2	1.11	1.13	1.1	1.41	1.09	1.09		
	c18		0.22	0.3	0.22	0.33	0.38	0.36	0.27	0.27		
	c20		0.006	0.014	0.007	0.01	0.017	0.009	0.01	0.01		
	total		1.69	2	1.77	1.91	1.88	2.28	1.84	1.84		
95% DOP	c14		0.62	0.72	0.46	0.57	1.3	1.45	1.5	1.46		
	c16		2.85	2.78	3.03	3.22	2.99	2.78	2.88	3.01		
	c18		0.3	0.24	0.25	0.31	0.39	0.28	0.34	0.3		
	c20		0.007	0.003	0.004	0.006	0.009	0.006	0.028	0.008		
	total		3.97	3.74	3.74	4.11	4.69	4.52	4.75	4.78		
4th Housing	c14		0.3	0.36	0.29	0.3	0.27	0.32	0.39	0.35		
	c16		0.63	0.96	0.91	0.94	0.75	0.99	0.98	1.17		
	c18		0.12	0.17	0.23	0.25	0.28	0.27	0.25	0.33		
	c20		0.004	0.003	0.008	0.008	0.01	0.009	0.008	0.009		
	total		1.05	1.49	1.44	1.5	1.31	1.59	1.63	1.86		
Mist-on	c14	2.14	1.32	1.04	0.5	1.06	2.03	2.43	2.15	1.72		
	c16	2.29	2.28	2.2	2.7	2.56	2.74	2.72	2.53	2.92		
	c18	0.17	0.38	0.29	0.28	0.28	0.41	0.24	0.17	0.32		
	c20	0.02	0.008	0.009	0.009	0.006	0.005	0.005	0.004	0.01		
	total	4.62	3.99	3.53	3.49	3.91	5.19	5.4	4.85	4.97		
Clean Air All filters in	c14											2.54
	c16											3.56
	c18											0.52
	c20											0.014
	total											6.63

Table B5 Evaporation Rate Experiment Vapor Measurements

		Concentration (mg/m^3)			
sample		Housin	Coalescing Filter	Pocket Filter	95% DOP Filter
1st	c14	0.72	1.24	2.64	2.02
	c16	1.68	2.06	2.62	3.13
	c18	0.47	0.25	0.3	0.21
	c20	0.014	0.006	0.006	0.003
	total	2.78	3.56	5.56	5.36
2nd	c14	0.51	0.89	2.25	0.15
	c16	1.13	2.23	2.67	2.93
	c18	0.32	0.32	0.24	0.2
	c20	0.012	0.006	0.006	0.006
	total	1.97	3.45	5.17	3.29
3rd	c14	0.43	0.68	1.8	0.12
	c16	1.15	2.32	3.06	3.09
	c18	0.34	0.33	0.33	0.21
	c20	0.014	0.007	0.006	0.004
	total	1.93	3.34	5.2	3.43
4th	c14	0.32	0.5	1.32	0.09
	c16	0.86	2.04	2.99	2.74
	c18	0.26	0.36	0.3	0.15
	c20	0.019	0.008	0.006	0.005
	total	1.58	2.92	4.61	2.99
5th	c14	0.25	0.44	0.82	0.09
	c16	0.84	2.33	2.6	2.74
	c18	0.3	0.48	0.23	0.24
	c20	0.01	0.01	0.005	0.004
	total	1.4	3.26	3.66	3.07
6th	c14	0.094	0.19	0.27	0.05
	c16	0.43	1.01	1.44	0.64
	c18	0.17	0.43	0.38	0.47
	c20	0.011	0.012	0.005	0.007
	total	0.71	1.64	2.1	1.17

Table B6 Daily Background Vapor Measurements: Concentrations and Composition

Day	Concentration (mg/m^3)
1	0.048
2	0.134
3	0.158
4	0.081
5	0.444
6	1.432
7	0.568
8	0.634
9	0.224
11	0.207
12	0.216
13	0.077
14	1.05
average	0.405615

Average Backgroung Vapor Composition

%c14	0.412
%c16	0.53
%c18	0.039
%c20	0.018

Table B7 Fluid Samples Composition

Composition of Drain Samples

	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9	day 11	average
%c14	0.093	0.0905	0.0845	0.0785	0.0735	0.0825	0.0835	0.079	0.0755	0.082
%c16	0.378	0.381	0.3855	0.3725	0.378	0.3595	0.3575	0.353	0.3535	0.369
%c18	0.4255	0.4265	0.426	0.4435	0.4505	0.448	0.451	0.458	0.459	0.443
%c20	0.1035	0.103	0.1035	0.1055	0.098	0.1105	0.1085	0.1095	0.112	0.106

Composition of Conditioning Nebulizer "Start" Samples

	day 1	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9	average
%c14	0.1145	0.1145	0.1145	0.116	0.113	0.117	0.1165	0.114	0.113	0.114
%c16	0.3725	0.3595	0.37	0.3795	0.3825	0.3655	0.359	0.361	0.3595	0.368
%c18	0.411	0.424	0.419	0.405	0.405	0.413	0.422	0.4225	0.4205	0.416
%c20	0.1015	0.1015	0.0965	0.096	0.0995	0.104	0.1015	0.1025	0.1065	0.101

Composition of Conditioning Nebulizer "Stop" Samples

	day 2	day 3	day 4	day 5	day 6	day 7	day 8	day 9	day 11	average
%c14	0.1135	0.115	0.1145	0.113	0.111	0.114	0.1145	0.1145	0.114	0.114
%c16	0.373	0.3785	0.3755	0.364	0.364	0.366	0.364	0.364	0.3515	0.367
%c18	0.4125	0.4095	0.413	0.4225	0.425	0.417	0.417	0.417	0.4315	0.418
%c20	0.101	0.0965	0.0965	0.0995	0.0995	0.103	0.104	0.104	0.103	0.101

Table B8 Fluid Recovered from Drain and Filters

days		fluid nebulized (g)	fluid recovered (g) drain	coalescing	pocket	95% DOP
1 to 2		1158	515	204	221	9
2 to 3		1252	582	198	239	13
3 to 4		872	361	132	149	12
4 to 5		1124	500	199	164	15
5 to 6		1718	855	301	237	29
6 to 7		1689	822	353	214	51
7 to 8		1458	722	227	200	20
8 to 9		1301	654	207	169	25
9 to 11		3606	2036	235	645	54
	totals	14138	7047	2056	2238	228

Appendix C

Statistical Analyses

STATISTICAL ANALYSES, DATA and RESULTS

For each p-value cited in this paper, a linear regression was run to determine if a correlation existed between two variables. If the slope of the regression at a certain confidence interval was non-zero, a correlation between the variables was said to exist at that confidence level. The following tables list the data, the regression slope, the 95% confidence intervals of the slope, and the p-values for each of the nine statistics cited in the text.

1. "Mist-on" alkane vapor concentration vs mass on filters, housing contribution subtracted

Mass on all filters (g)	Vapor Concentration (mg/m^3)
434	2.54
884	1.64
1177	1.65
1555	2.01
2122	3.48
2740	3.41
3187	2.82
3588	2.71

Regression slope: 0.00037
95% confidence interval: (-0.00015, 0.000883)
p-value : 0.1238

2. "Mist-on" commercial mineral oil vapor concentration vs mass on filters, housing concentration not subtracted out (not known)

Day	Vapor Concentration (mg/m^3)
2	4.16
3	3.17
4	4.28
5	4.94
6	4.42
7	3.45
8	4.01
9	3.42
10	5.2
11	4.74
12	5.31
13	4.15

Regression slope: 0.0742
95% confidence interval: (-0.0514, 0.1999)
p-value: 0.2149

3. "Clean-Air" vapor sample for coalescing filter, housing contribution subtracted

Mass on coalescing filter(g)	Vapor concentration (mg/m^3)
204	1.4
534	0.66
733	1.52
1034	1.90
1387	2.62
1614	1.76
1821	2.10

Regression slope: 0.00071
95% confidence interval: (-0.00015, 0.001574)
p-value: 0.07912

4. "Clean-Air" vapor sample for pocket filter, housing contribution subtracted

Mass on pocket filter (g)	Vapor concentration (mg/m^3)
221	3.19
460	2.03
609	2.10
773	2.23
1010	3.62
1224	2.98
1424	3.13
1593	3.38

Regression slope: 0.000542
95% confidence interval: (-0.0004, 0.001485)
p-value: 0.2024

5. "Clean-Air" vapor sample for 95% DOP filter, housing contribution subtracted

Mass on 95% DOP filter(g)	Vapor concentration (mg/m^3)
9	2.2
22	1.58
34	1.76
49	1.99
78	2.69
129	2.19
149	2.63
174	2.54

Regression slope: 0.004039
95% confidence interval: (-0.0017, 0.009807)
p-value: 0.13

6. "Clean-Air" vapor sample for coalescing filter

Mass on coalescing filter(g)	Filter Weight loss (g)
204	8
402	8
534	9
733	29
1034	9
1387	9
1614	10
1821	14

Regression slope: 4.455
95% confidence interval: (-78.67, 87.58)
p-value: 0.8993

7. "Clean-Air" vapor sample for pocket filter

Mass on pocket filter(g)	Filter weight loss (g)
221	6
460	5
609	5
773	6
1010	6
1224	6
1424	6
1593	6

Regression slope: 0.000467
95% confidence interval: (-0.00037, 0.001306)
p-value: 0.2149

8. "Clean-Air" vapor sample for 95% DOP filter

Mass on 95% DOP filter(g)	Filter weight loss (g)
9	9
22	5
34	6
49	5
78	4
129	5
149	5
174	4

Regression slope: -0.01541
95% confidence interval: (-0.0357, 0.00489)
p-value: 0.1056

9. Tetradecane concentrations versus water vapor pressure, "Mist-on" vapor samples using alkane mixture

Water vapor pressure (kPA)	Tetradecane concentration (mg/m^3)
1.19	1.15
1.14	0.88
0.95	0.34
1.08	0.89
1.40	1.87
1.59	2.26
1.34	1.97
1.40	1.81

Regression slope: 3.1469
95% confidence interval: (2.4199, 3.8738)
p-value: 1.46e-5

Appendix D

Estimation of Vapor Sampling Losses

Estimation of Vapor Sampling Losses

During the vapor sampling experiments in this work, some of the vapor entering the sampling line may have collected on the walls of the sampling train or on the glass fiber filter used to remove aerosols from the sample airflow. If vapor was lost to the sampling train before reaching the carbon tube, vapor concentrations reported in this paper would underestimate the actual concentration. Tests were run with both dodecane ($C_{12}H_{26}$) and a commercial mineral oil to investigate the extent of these vapor losses.

Dodecane experiments

The HEART nebulizer was used to introduce a dodecane aerosol into the test set-up used in the experiments presented in this paper. Vapor was sampled from the same location as in the paper. The sampled air first passed through a glass fiber filter to remove aerosol as in the paper. The flow was then split; one-half of the flow was drawn through a carbon tube alone, whereas the other one-half of the flow was drawn through another glass fiber filter and then a carbon tube. By comparing the mass of vapor collected on the carbon tube that had only filter proceeding it to the mass of the vapor collected on the carbon tube with two filters proceeding it, sampling losses could be estimated. The results were:

Filters proceeding tube	Concentration (mg/m^3)	% difference
1	4.30	4.0
2	4.13	

Since small variations in concentration are expected due to experimental error in sampling and in carbon tube analysis, the results of this experiment were compared to the results of an experiment in which air flow was first sampled through a glass fiber filter and then split to two carbon tubes in parallel. The results from this experiment would suggest how much variability is inherent in the sampling technique. The results for the two tubes in parallel are as follows:

tube	Concentration (mg/m^3)	% difference
1	4.26	3.2
2	4.40	

Since the variability in the results of the first experiment resemble the variability in the results of the second experiment, it appears unlikely that the sampling train is removing dodecane vapor.

Commercial mineral oil experiments

Tests, as described in the dodecane experiments above, were run for a commercial mineral oil to determine vapor sampling losses. The results for two vapor samples:

filters proceeding	Concentration (mg/m^3)	% difference
1	1.70	25.0
2	1.28	
1	1.98	40.4
2	1.18	
	average	33

Once again, these results were compared to samples measuring the variability of the measurement technique. These samples were not taken as in the dodecane experiments described above. The two carbon tubes were inserted 180^0 apart on the circumference of the duct; they were not in parallel. As Raynor demonstrated that the duct was well-mixed for aerosol, the assumption that the vapor concentration should be equal at the two sampling location seems reasonable. The samples used to determine variability did not use the HEART nebulizer to introduce mist. The first sample listed below used the conditioning nebulizer; the remaining three measured evaporation of oil from loaded collector components. Although not identical to the above tests, they still show the variability expected in vapor measurements in this system using commercial mineral oil as a test fluid.

sample	Concentration (mg/m^3)	% difference
conditioning nebulizer	6.25 6.66	6.2
first housing	2.68 3.70	27.6
second housing	2.60 2.94	11.6
third housing	1.99 1.67	16.1
	average	16

From the first set of experiments, 33% of the mass would be expected to be lost before the commercial mineral oil reached the carbon tube. However, the second set of experiments

show a variability of 16% for vapor measurements in this system. Thus, by taking the difference in variability found from the first and second set of experiments, 17% of the commercial mineral oil could be estimated to be lost to the sampling train, causing vapor concentrations to be underestimated. If the variability in measurements caused the vapor collected on the tubes in the first set of experiments to be closer than they actually were, the mass lost to the sampling line would be even larger.

Appendix E

Mass Selective Detector Response to Ion 57 for Four Alkanes

Mass Selective Detector Response to Ion 57 for Four Alkanes

The following table lists the mass selective detector's response to known masses of tetradecane ($C_{14}H_{30}$) , hexadecane ($C_{16}H_{34}$) , octadecane ($C_{18}H_{38}$), and eicosane ($C_{20}H_{42}$). These values list the response for eight GC-MS injections for an alkane solution containing each of the four alkanes.

Injection #	MS response (arbitrary peak area units/ mg alkane)			
	C14	C16	C18	C20
1	120099	118426	118916	109931
2	111435	114920	122383	114742
3	88694	91698	97716	91744
4	85196	95916	90428	84813
5	117569	122283	130266	109495
6	119783	127712	136557	122759
7	105353	111975	118041	110289
8	82309	91759	92550	86662
Average	103804	108086	113357	103805

Appendix F

GC-MS Analysis of Commercial Mineral Oil

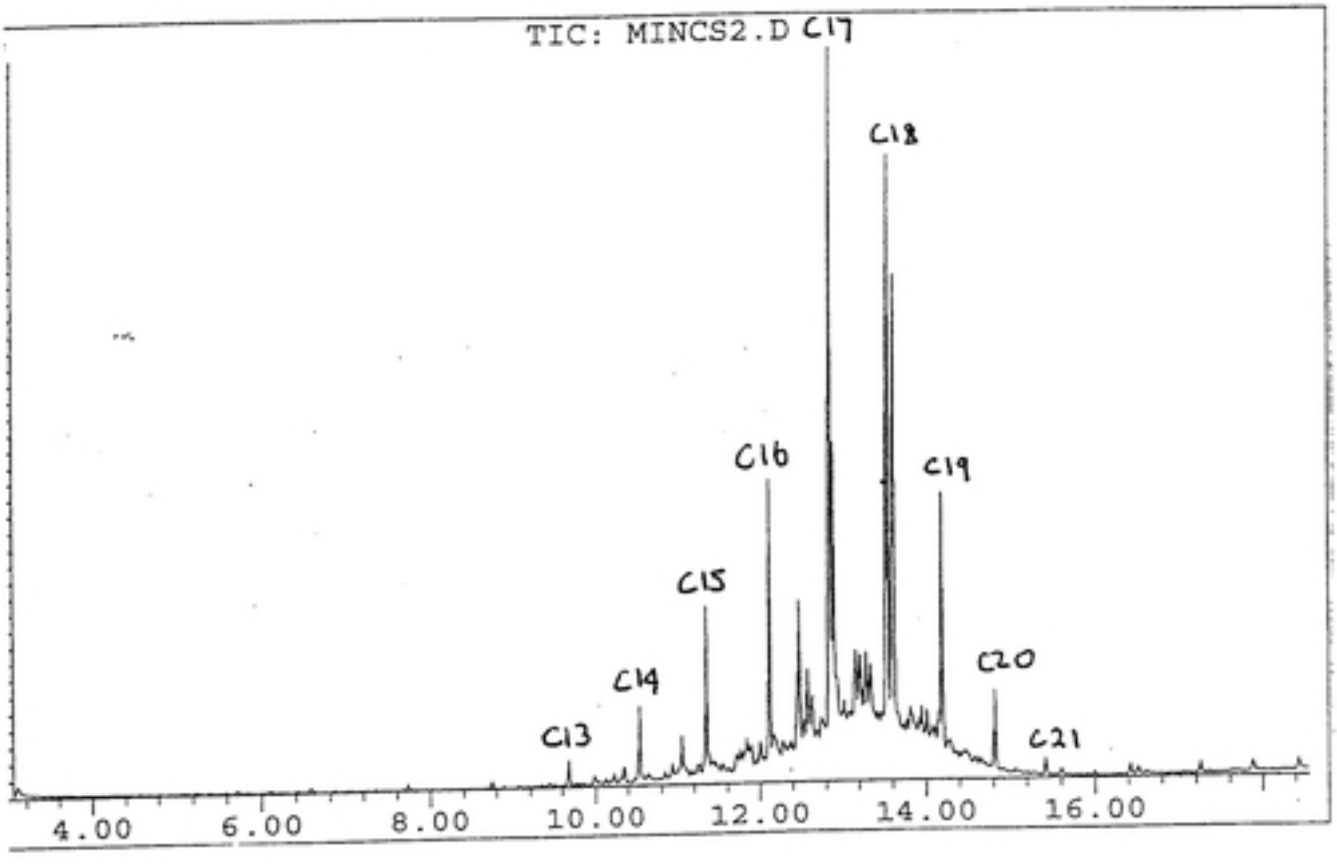

Figure F1: GC-MS analysis of commercial mineral oil

Appendix G

Estimation of Saturation Vapor Concentration

Estimation of Saturation Vapor Concentrations

Raoult's Law was used to estimate the saturation vapor pressure for vapor in equilibrium with fluid drained from the collector. Raoult's Law relates the vapor pressure of fluid component i, p_i, to its mole fraction, χ_i, and saturation vapor pressure, $p_{sat,i}$, where

$$p_i = \chi_i \cdot p_{sat,i} \qquad \text{(G1)}$$

The mole fractions for each alkane in the drained fluid are given in Table B7 and are as follows:

$\chi_{C14} = 0.099$
$\chi_{C16} = 0.392$
$\chi_{C18} = 0.418$
$\chi_{C20} = 0.090$

The saturation vapor pressures were estimated by Raynor [11]; he used a linear regression of Lange's Antoine Equation from data for C5-C10 to estimate the saturation vapor pressures for C14-C20. His results for T = 295 K are as follows:

$p_{sat,c14} = 0.008755$ mmHg
$p_{sat,c16} = 0.000788$ mmHg
$p_{sat,c18} = 0.0000708$ mmHg
$p_{sat,c20} = 0.00000637$ mmHg

A sample calculation for the estimation of saturation concentration of tetradecane vapor follows:

$$p_{c14} = 0.099 * 0.008755 \text{ mmHg} = 0.000871 \text{ mmHg}$$

This saturation vapor pressure can then be converted to a saturation concentration using the following formula:

$$\text{conc } (\mu g/m^3) = \frac{\text{conc (ppm)} * P_{atm} * MW}{R * T} \qquad \text{(G2)}$$

where conc (ppm) is the ratio of alkane partial pressure from eq (G1) to total pressure multiplied by 1e6
P_{atm} is atmospheric pressure- Pa
MW is molecular weight of alkane- g/mol
R is gas constant- $(Pa\text{-}m^3)/(mol\text{-}K)$
T is temperature- K

$$\text{tetradecane conc (ppm)} = \frac{0.000871 \text{ mmHg}}{760 \text{ mmHg}} * 1e6 = 1.146 \text{ ppm}$$

$$\text{tetradecane conc } (\mu g/m^3) = \frac{1.146 * 101325 * 198}{8.314 * 295} = 9374 \text{ ug/m}^3$$

$$= \mathbf{9.37 \text{ mg/m}^3}$$

Similar calculations were done for each of the other alkanes to estimate their saturation vapor pressures in equilibrium with the drained fluid, the results:

hexadecane saturation concentration = **3.79 mg/m^3**
octadecane saturation concentration = **0.41 mg/m^3**
eicosane saturation concentration = **0.009 mg/m^3**

The total concentration is the sum of the concentration of the individual components, 13.59 mg/m^3.

Appendix H

Recommendations for Further Research

evaporation. Finally, as this work shows that mineral oil in the vapor phase is penetrating through the collector, work should be done on ways to collect this vapor before it is released to the atmosphere or re-circulated to the workroom.

Field work is needed to determine the extent that evaporation found in a controlled laboratory setting is occurring in an industrial setting. Vapor samples need to be taken downstream of the collector both during operational and off-line shifts. Vapor samples should also be taken in the plant workroom to determine exposure to workers. Long-term tests would be more likely to detect changes in vapor concentration levels as a function of mass loaded onto the filters than the nine-day experiment presented here.